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AN INTRODUCTION TO BIOLOGY

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AN INTRODUCTION TO BIOLOGY

CHAPTER I

FUNDAMENTALS

Shortly after the tragic war commenced in 1914, a German writer, Bernhardi, startled the newspaper-reading public with the statement that war was a biological necessity. People began to ask what a "biological necessity" was, anyway, and what was "biology." Other events in the war brought the word still more in the public eye until now it has become part of the stock-in-trade of the novelist. The public body is beginning to feel that biological discoveries may result in more disturbing effects than those of the chemist and engineer.

Biology, as we shall use the term, means the study of living creatures—living organisms is a better way to put it. It is the science that deals with that intangible phenomenon—life.

Biology (essentially arising in -the nineteenth century) grew out of the studies which we still call *Natural History*, and which were initiated many, many centuries ago, indeed, by primitive man, who was vastly concerned with his food supplies and his competitors in the jungle. History is vague about those who first produced our domesticated animals, and little is known of the biological observations and discoveries of the ancient civilisations of the East, which perished amidst the ruins of their empires.

We have to look to Aristotle (384 B.C.-322 B.C.) for the founding of the Science of Natural History, and for the first great effort at a classification of animals, with observations on their habits and structure. The study so ably founded declined to a much lower level, and then came that long barren period of the Middle Ages. A thousand years and more after the Greeks had made a fair beginning in the quest of things alive, a fresh start was made by Vesalius, a Belgian, whose work, however, was more closely associated with the University of Padua in Italy, where from 1537, as Doctor of Medicine, he lectured on Anatomy and Surgery. Vesalius' great work was anatomical, the study of the structure of the human body, but at the same period the study of the functions of the parts of the human body received its great impulse through the discovery of the circulation of the blood by an Englishman, William Harvey. After his early studies, Harvey also left the country of his birth and went to Padua to study medicine under the great master, Fabricius. His discoveries were published after his return to England, when he became Physician to St. Bartholomew's Hospital in 1609 and Physician to King Charles I. Thus Anatomy, the study of structure, and Physiology, the scienҫe which attempts to answer the question, "What is happening in the structure when it is alive?" commenced their great period of development. For many years after this the study of function remained closely linked with human anatomy and medicine.

As the years passed on a succession of pioneers penetrated more and more deeply into the mystery of living things. Animals and plants were collected, described and named, and their anatomy was studied in detail until the most minute structures came to be investigated. Quite early in the seventeenth century the microscope, newly invented, was applied to the study of plant and animal structure. This was the beginning of a new era. The vast world of minute living organisms (invisible to the naked eye, but so important to-day in disease and economics) was gradually revealed. Amongst the first of these discoveries the pictures of the cellular structure of plants by Hooke, Grew and Malpighi are of the greatest interest, for they foreshadowed the cell theories of the nineteenth century and the fundamentals of modern biology. So with the parallel development of studies in anatomy (gross and minute), classification of animals and plants, and studies of function, we are brought to the end of the eighteenth century. Linnæus had produced his great catalogue of animals and plants and established the system of naming living organisms which we use to-day. The discovery of oxygen in 1774 by Priestley was destined to exert a profound influence upon the advance of physiology; it was impossible to understand the real meaning of respiration before then. Also, thanks to the remarkable advance in studies of comparative anatomy, the belief in a theory of evolution, several times suggested in a nebulous way by earlier philosophers, was assuming definite shape. (Erasmus Darwin, 1731-1802, grandfather of Charles Darwin, Buffon, 1707-1788, and very especially Lamarck, whose theory still holds the field with that of Darwin, are names to be noted.)

The nineteenth century brought the discovery of an identity of structure between animals and plants, the discovery of the cell as the unit of structure. Intimately connected with this was the discovery of *Protoplasm*, the semifluid substance of the cell which is endowed with the qualities of life—the real living substance. The name was given in 1840 to the living substance of plants. It had been observed in 1835 in animals and called *Sarcode*. In 1861 it was definitely shown that sarcode and protoplasm were identical. The general acceptance amongst scientists of the theory of evolution, due largely to the work of Charles Darwin, provided the complete key to the position thus gained, for the evidence indicated that not only had animal life as we know it evolved—*i.e.*, originated—by descent from lower and more simple types, but that both animals and plants had had a common ancestry. The fundamental phenomena of life are, in fact, the same in animals and plants.

What gravitation has been to the astronomer the concept of evolution has been to the biologist. The knowledge that there has been a continuous stream of life down the ages, so that the animal and plant worlds resemble a giant genealogical tree with ever multiplying ramifications and divergencies, a tree which has taken millions of years for its unfolding, has entirely altered our viewpoint and methods of research. If we cannot study the function of the thyroid gland in man, we may be able to do it in one of the lower animals. A realisation that the same essential units of structure are present in plants as in animals suggests that a study of certain growth abnormalities in plants should be of interest to one searching for the cause of cancer. The knowledge that the mechanism of reproduction and heredity is essentially the same throughout the world of living things indicates that we may discover facts of the greatest importance to man by investigating the inheritance of the characters of a small fly. With such an example we can work through many generations in a year, an impossible thing with the slow-breeding higher animals.

So the field has widened, and, with increasing interest and the realisation of the direct value of biological study, more and more workers have been attracted to the field. The microscope has been developed to a power hitherto undreamt of, new technique and remarkable instruments and experiments have been invented and devised, and from purely descriptive natural history we have reached a stage in which man is beginning to learn something of the "mechanism" of life and the possibility of controlling it.

It is now desirable that we should turn to that unit of structure, the *Cell,* which is of such great importance in modern biology. The cell theory of animal and plant structure was not launched until 1838, the year in which two friends, Schleiden, a botanist, and Schwann, an anatomist, compared notes and commenced to collaborate, yet these tiny units of living matter had been seen and depicted 175 years before, when Hooke examined a thin section of cork, and Malpighi and Grew applied the microscope to thin sections of plant stems. Even Schleiden and Schwann did not realise at first the true nature of cells. That is why the term "cell" is a misnomer in biology. We commonly think of cells as little chambers, and that is how they appeared to the early workers with the microscope. They attached too much importance to the cell wall. Gradually it came to be realised that the essential part of the cell was the living substance, protoplasm; a cell wall might or might not be differentiated. The name "cell" has, however, become a fixture. Instead, therefore, of a hollow chamber, we regard a cell as a small, usually microscopic, mass of protoplasm, generally containing a smaller body of modified protoplasm called the nucleus, and possibly enclosed in a membrane, the cell wall. All living things are composed of cells and their products, but the numbers of these units present, their diversity and specialisation, vary enormously. At one end of the scale there are microscopic creatures consisting of only a single cell; at the other end we have the highly complex multicellular animals containing millions and millions of cells specialised in form and function—*e.g.*, muscle cells, nerve cells, bone cells, gland cells, and so on. A generalised cell is illustrated in Fig. 1, and there are also shown the germ cells of a multicellular animal. On the whole, the student new to biology is probably more startled when he first sees under the microscope a living creature consisting of a single cell (like the famous amœba depicted in the figure) than when he studies the frog or man. Those who have seen the minute particle of semifluid substance which is an amœba, move about, capture food, digest it, respond to changes in its environment, and reproduce its kind, will understand that feeling. The cell substance, protoplasm, is the essence of life. It is this which is in some way different from all that is non-living. To discover its structure and composition, its response to stimuli, and its behaviour under varying conditions are fundamental efforts in biology. Yet protoplasm still holds its great secret.

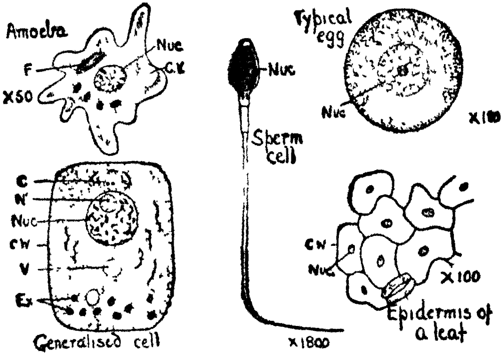

Fig 1. Cells. highly magnified
C. Centrosomes CV Contractile Vacuole CW Cell Wall. Ex. Products of cell life F Food particle N. Nucleolus Nuc Nucleus V Vacuole.

Very simple microscopic investigation enables us to distinguish between nucleus and surrounding protoplasm. The protoplasm of the nucleus contains certain different chemical substances, and its presence appears in most cases essential for the well-being of the cell. Thus it has been possible to cut a single-celled creature in two so that one part contains the entire nucleus. That part continues to live, the other soon dies. A human being (almost any other animal or plant might be taken as an example) arises from the product of two tiny germ cells (Fig. 1). These two cells must have contained factors for all the characters inherited from their parents. There is considerable evidence to show that the mechanism for this is situated in the nucleus. Obviously, the complexity of the nucleus must be far greater than is visible with the highest powers of the microscope. A glimpse, however, of this complexity is seen when a cell divides.

The cell is the unit of structure; it is also a unit of function, for all the activities which are characteristic of life take place within the cell.

The simplest living creatures are microscopic and consist of one single cell; in this group of organisms it is very difficult to distinguish between plants and animals. Of course, this age-old grouping of living creatures was based upon the evident differences between the higher plants and animals. An oak-tree is clearly very different from a tiger. The differences fade away amidst the unicellular forms of life, and this is what one would expect if plants and animals had had a common ancestry. The bacteria, which are the most minute of all organisms (and so well known as mere names to the everyday world), can scarcely be said to be plants or animals; the distinction simply has not arisen. Now if we observe a member of this unicellular group, such as *Amœba** we see that it can move about, its protoplasm appears to be able to discriminate between substances it accidentally touches, it flows round and captures food particles which it can digest, it is sensitive and responds to changes in its environment, it grows, and having reached a certain size it reproduces by dividing into two or more little amœbæ. Special tests would show that it breathes and also that it excretes waste matter. It presents, in short, all those fundamentals which enable us to say that here we have a live thing, although at the same time we find it impossible to define life. These fundamentals, few in number, are universal amongst the infinite multitude of different sorts of living creatures. Structures may vary to an extraordinary degree, but evidently the activities which they perform are everywhere much the same.

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* Common in ditches and ponds, present in the soil, and with relatives parasitic within the bodies of other animals, including man.

The amazing substance, *Protoplasm*, appears to be composed of only a small number of chemical elements. It is, however, neither a chemical compound nor a simple mixture of such. Rather would it appear to be a complex of systems—an organised structure. We find present a large percentage of water (75 per cent.), and various chemical substances of which three classes, proteins, carbohydrates, and fats, predominate, together with certain mineral salts. The reader nonversed in chemical lore knows what fats are like, and he probably knows that they are compounds of carbon, hydrogen, and oxygen. He cannot help but be familiar with some carbohydrates—sugars, starch, cellulose (also compounds of carbon, hydrogen, and oxygen). The proteins, on the other hand, are less familiar, but they are the fundamental substances responsible for the phenomena known as life. They consist of carbon, hydrogen, oxygen, nitrogen, and usually sulphur or phosphorus, or both. Whilst proteins are built up of a few elements, these are combined in such elaborate structures that countless varieties may exist. It is now pretty clear that protoplasm could not exist except for proteins.

There seems no end to the number of possible compounds of carbon, hydrogen, and oxygen (with or without other elements). This is all due to carbon atom linking to carbon atom until very big molecules result. But this is not all. There are two tartaric acids known, although each has the same number and kinds of atoms in its molecule. The possibility of this is due to the fact that the atoms may be arranged in the tartaric acid molecule in two different ways so that the two different acids bear the same relation to one another as one's right hand to the left, or a reflection in a mirror to the thing itself. Come now to the proteins. Instead of three or four atoms in the molecule we may find thousands. On top of this there is the same kind of possibility of difference in internal arrangement of atoms—in this case, however, not two possibilities, but hundreds of thousands. And so we have the explanation of the fact that whilst the red colouring substance of the blood in *all* the different vertebrates is *Hæmoglobin*, yet there is one hæmoglobin in human blood, another in the horse, another in the pig, and so on, and so on.

Now imagine that living protoplasm is not even a mixture of such proteins, but an elaborate structure in which they play the fundamental part, and you will realise the difficulties in the discovery of the phenomena of life.

What goes on, then, in a small mass of living protoplasm, such as a single cell? It is unstable, with physical and chemical processes constantly taking place. It is this constant change which is the characteristic of life, and to the sum total of it all we apply the term *Metabolism*. But metabolism is not independent of the environment. One result of the activity going on is that the protoplasm increases in amount; it grows. Material is required from without to supply the demands of growth and also to make up for the substances which have broken down and given up their store of energy. Waste substances which have been formed must be removed. So with life goes concurrently the need of food (nutrition) and the removal of waste (excretion). All the activities which living creatures exhibit demand supplies of energy. In by far the greater number of cases, though not in all, energy is ultimately set free by processes of oxidation. For this purpose living protoplasm requires supplies of oxygen, and we use the term *Respiration* for the intake and use of this substance and the complementary passage out of certain products which result.

It is practically impossible for living protoplasm to find materials which without change it can attach to its own complicated and very special structure. It has, however, the power of bringing its food into a form which can be utilised. Green plant cells can do much more in this way than animal cells, and herein we are provided with one of the distinguishing characters of the two great groups of living things. It is typical of plants that they can build up fats, carbohydrates and proteins from very simple substances like water, carbon dioxide, nitrates, etc. Animals require their foodstuffs already in the form of complex organic compounds. This remarkable faculty of plants depends upon the presence of the green substance, chlorophyll, and the energy of sunlight. Without plants and photosynthesis it is not possible to conceive of the existence of the animal world as we see it to-day.

If we lower the temperature of the environment we slow down the chemical changes which are inseparable from living protoplasm. This is exhibited by the retardation of plant growth at low temperature. Animals whose temperature is the same as the environment tend to become sluggish, and many fall into a kind of sleep. If the lowering of temperature merely stopped the chemical actions without destroying any structure, there would be no reason why, after being frozen for some time, protoplasm should not take up its activity again. This is often the case, and it is borne out by the fact that it is possible to expose bacteria to a temperature of liquid air without preventing them from continuing their life activity after an elevation of temperature.

Why, then, cannot most animals withstand freezing? The answer is that since protoplasm contains a large percentage of water, the freezing of this and the formation of ice crystals shatters the complex structure which is so special a feature of protoplasm, or withdraws the water. Nothing could show more simply that living protoplasm is more than a collection of certain chemical substances. Higher animals with a more complex physiology cannot stand exposure to cold for other reasons, and for the human being a drop in the temperature of the body from 37·5° to 27° C. means very severe damage.

The optimum and the maximum temperature varies considerably for the protoplasm of different living things, but there are very few animals which will withstand a temperature of 45-50° C. Striking exceptions are the few animals and plants which have become adapted to life in hot springs.

We have not defined life, but we can usually recognise it. Sometimes, however, this is a matter of difficulty, and one is faced with such puzzles as that of any ordinary seed in the dry state or even of a hibernating hedgehog. The usual manifestations of life are absent. We cannot say they are dead; we can speak of them as lifeless. It has been ably said that they are like a clock which has been wound up but requires a touch on the pendulum to set it going. Using the same analogy, a dead creature might be compared to a broken clock.

CHAPTER II

THE FEEDING OF ANIMALS AND PLANTS AND THE CHEMICAL PHENOMENA INVOLVED

It has been said that all the activities of animal life may be resolved into the consequences of two potent driving forces—the fulfilment of the urge for food and for reproduction. Certain it is that nothing could be more interesting than the diversity of methods exhibited by living organisms for the acquirement of food and the processes whereby this is utilised.

It is practically only since the war that one has really appreciated the fact that "Man cannot live by bread alone"; bread is not sufficient to supply a human being (or, for that matter, a bird or mammal) with an adequate quantity of what we regard as food substances. Something else is involved. At present it is thought to be small quantities of somewhat problematic substances known as *Vitamins*. The empirical knowledge of our ancestors of the efficiency of fruit in the prevention of scurvy, and of cod-liver oil in rickets, has in the past ten years come into its own.

Manifestly it would be both impossible as well as undesirable to give a catalogue of animal and plant feeding methods in these pages. Instead we shall tackle the more fundamental problems of how non-living foreign stuffs are brought into the complex system of living protoplasm.

It is, perhaps, excusable if for a second we theorise on the probable method of nutrition characteristic of the first and most simple forms of life. To-day there are three modes of nutrition (with possible combinations) met with in nature, and these are:

1. *Holophytic.*—The utilisation of simple aqueous and gaseous inorganic substances so characteristic of the green plants, and the phenomenon of *Photosynthesis* by which these simple substances are built up into fats, carbohydrates, and proteins.

2. *Holozoic.*—The typical animal type of nutrition —the intake of particles of solid food consisting of proteins, fats, and carbohydrates which are, or have been, parts of other animals and plants.

3. *Saprophytic.*—The absorption of organic substances in fluid form. Characteristic of a few animals and of plants without chlorophyll—*e.g.*, fungi (mushrooms and mildews)—and bacteria.

Probably *Saprophytic* nutrition is the most ancient and simplest type. Bacteria feed solely in this manner to-day. The higher animals are all dependent directly or indirectly on the green plants. Possibly, therefore, the evolution of the remarkable mechanism of photosynthesis came next, and holozoic feeding last.

It was originally believed that plants obtained all their food supplies from the soil by means of the roots, and it was not until the beginning of the nineteenth century (1800-1845) that it was completely realised that the air is actually the source of all the carbon of green plants. The chlorophyll of plants, which gives the dominant character to the land areas of the earth's surface, is an essential factor in the process. It is not remarkable that "chlorophyll" has been termed the most wonderful pigment substance in the world; without it there would be no animal life as we know it to-day.

Chlorophyll is found in the plant cells in little bodies which lie in the protoplasm outside the nucleus. As a matter of fact, the name is somewhat loosely applied to four different coloured substances: Chlorophyll A, Chlorophyll B, Carobin (red), and Xanthophyll (yellow).

In the presence of light the chloroplastids convert carbon dioxide (which is absorbed by the leaves from the air) and water (absorbed from the soil) into carbohydrates. The phenomenon is known as photosynthesis. It is not difficult to demonstrate the end results, and they may be summed up in the equation

$$\underbrace{6\mathrm{CO_2}}_{\text{carbon dioxide}} + \underbrace{6\mathrm{H_2O}}_{\text{water}} = \underbrace{\mathrm{C_6H_{12}O_6}}_{\text{sugar}} + \underbrace{6\mathrm{O_2}}_{\text{oxygen.}}$$

The exact steps in this synthesis, so important to the continuation of life on the earth, have so far eluded man's efforts of discovery. Theories there are, of course, without number. The schoolgirl is often told of the process as if all were known, the favourite explanation being that carbon dioxide and water are combined to give formaldehyde, and that this is changed into sugar. The truth is there is no more evidence for believing that formaldehyde is the first stage than there is to support other theories.

Only a short time ago there was no evidence that carbon dioxide and water could be made to combine in the chemical laboratory without an expenditure of energy that was quite incomparable with what goes on in plants. If the discoveries of Professor Baly and his co-workers at Liverpool, published recently, turn out to be correct, quite another aspect of the matter must be faced. Baly and his colleagues believe that they have synthesised carbohydrates directly from carbon dioxide as the result of exposing water through which carbon dioxide is bubbled to *visible* light. The water contained a suspension of a powder (cobalt carbonate). The theory is that the carbon dioxide becomes concentrated (more correctly, adsorbed) on the surfaces of the suspended particles, and then is photosynthesised to carbohydrate.

It is stated that the total yield of carbohydrate is quite comparable with that produced in plants. Probably there is still a long way to go before the full explanation of the photosynthesis of carbohydrates and the manufacture of proteins in plant leaves is understood.

Our short study of animal nutrition will be confined chiefly to our present knowledge of how the food substances become incorporated into the animal body. Since animal foods are in a far more concentrated form than the simple substances absorbed by plants, there is no need for an extensive outer absorbing surface, and so, instead of leaves and roots, we usually find an internal cavity, or tube, into which food is taken, and where it can suitably be treated. The passage of food into this alimentary canal is not really passage of food into the animal body, and it is possible and frequent that substances entering this food space pass through it, or are thrown out the way they came in, without ever having entered a single living cell.

It is often thought that the processes of *Digestion* which go on in the alimentary canals of animals are chemical processes involved solely in making soluble the substances taken in, so that the products may easily pass through the cells lining the canal (the stomach and intestine in man) and eventually reach all parts of the body. The matter is not nearly so simple. The living protoplasm will only "accept" certain combinations. We may eat protein, say, in the form of mutton or fish, but the proteins of sheep muscle or fish muscle are not the same as those of human protoplasm. It is not sufficient, therefore, that these proteins be brought into soluble form. They must be converted into substances which can be built up by the human protoplasm into its own proteins. The same applies to the carbohydrates. Starch is insoluble in water and cannot pass through the cell walls into the protoplasm; it cannot, therefore, pass through the alimentary canal walls in this form. It must be converted into something else. It is changed by digestive juices into sugar. But it must be a sugar that can be utilised. Bearing this in mind, it is possible to modify an old adage to read: " What is one animal's meat is another animal's poison."

Restriction to some particular type of diet is best seen, perhaps, amongst the insects, where one species is often associated with one particular type of plant. Remove the latter, and the insect disappears. Other remarkable examples are the clothes moths obtaining everything from a diet of wool, and the white ants constructing all their organs on a diet of dried wood. A less specialised form of restriction is that of carnivorous and herbivorous animals. Sheep would find a diet of meat impossible, and a tiger would soon look very sick if provided with meals of grass!

In many of these cases, however, the inability to utilise other food sources is a question of structure rather than, or as well as, chemistry. Thus, herbivorous animals have much longer food canals than carnivorous creatures. A tiger's teeth are specially adapted for killing and tearing its prey, a sheep's dentition is peculiarly modified for the purpose of grinding up grass. One dentition could not do the work of the other.

It is, perhaps, more surprising to find how diverse the foodstuffs of an animal can be rather than to find the restrictions. The chief foods fall into only three classes—Proteins, Carbohydrates, and Fats—and the mechanism of digestion is such that the means provided to digest one protein are usually capable of digesting a host of members of this class; the same thing applies to the fats and carbohydrates.

Digestion is brought about by the addition to the food of certain chemical substances known as *enzymes*. The chemical composition of these substances is still unknown. They are certainly remarkable, and if their recognition is a matter of modern times (since 1896), their activities have been known and blessed for thousands of years, since both the leavening of bread and the conversion of grape-juice into wine is the result of an enzyme produced by living yeast cells (yeast is a unicellular organism usually regarded as a plant).

The extraordinary thing is that the type of operation involved in all the digestive processes is the same, although the substances digested are so diverse. The operation may be illustrated by taking the case of the proteins. Chemical analysis has shown that the proteins are built up of molecules of amino-acids linked together. Enzymes which digest proteins break this linkage by the addition of a molecule of water. But the enzyme neither supplies the water *nor is itself used up in the process.* Although the action of an enzyme is, of course, absolutely different, it will serve as an analogy if we compare its influence to that of lubricating oil in an engine. The latter enables an action to go at greater speed, and although some of it may be destroyed, the necessity for continual oiling is generally due to simple loss by leakage.

We have explained that, with the addition of water, proteins split up into constituent amino-acids. The process is known as *Hydrolysis.* The digestion of carbohydrates and fats is also a process of hydrolysis.

Finally, after absorption of amino-acids, sugars, or the products of fat digestion into the living cells, it is enzyme activity again which results in the opposite process to digestion—*i.e.*, the rebuilding into the substances of the organism.

These digestive processes are accompanied by an infinite series of other interesting features. The enzymes may not be produced in the active condition, otherwise they might act on and destroy one another (there are three, for example, in pancreatic juice). They may need to come into contact at the proper place and time with something else which sets them off. Thus trypsin in the pancreatic juice of man is inactive until it reaches the intestine. Again, the pepsin of the stomach may successfully attack some of our very tough restaurant steak, yet it does not digest the walls of the stomach, because the walls produce an anti-pepsin which hinders such action. A tapeworm may live in the human intestine where all sorts of substances are being dissolved. It survives because it actually produces anti-ferments which antagonise the action of the digestive juices.

Since proteins are essential for the growth as well as the repair of waste of protoplasm, they are essential in all animal foods. Proteins alone will supply all needs—energy as well as repair substances. The limit, therefore, of diet restriction in animals would be some protein containing substance. Carbohydrates and fats are more economical for the production of energy, and so one usually finds a varying mixture of these with the proteins. The need for water and salts must be remembered, since 75 per cent. or more of an animal's body may be water.

Now we are brought to a curious problem. Recent practice has shown that in the case of man and also of his domestic animals a sufficiency of actual food substance may be present, and yet disorder may result which can be traced to the nutrition. The condition to which we are referring is not due to the presence of something deleterious in the food; it seems rather to be due to an absence. It was first noticed when scurvy was common on board ships in the days when diet was more restricted and fresh vegetables were missing. The food was not appetising, but the real cause of scurvy (found out many years later) was the deficiency of very small quantities of a substance present in fruit and vegetables. A small quantity of orange juice could, in fact, put matters right. Lime juice, since it can be stored for some time without loss of the precious substance, thus came into ship use. Such accessory food substances have been called *Vitamins*, and, since very little is yet known of their composition they have been labelled in a very general way. The one to which we refer above (anti-scorbutic vitamin) is called *Water Soluble C*.

Another disease clearly associated with a nutritional deficiency is beri-beri. This is prevalent amongst Eastern peoples, and is thus met with in some of our own Eastern colonies. After being a puzzle for a long time, it was eventually discovered to be due to a restriction of diet to white rice (polished rice as we know it—*i.e.*, without the husk). If unpolished rice is eaten, the disease does not arise, although most of us who relish the delicacies of a modern dinner would probably say that this was restriction enough in all conscience. The disease can easily be imitated in domestic fowls by feeding them exclusively on polished rice; a peculiar degeneration of the nerves results. The trouble, even when serious, can be cured *by the addition of rice bran*, or of other foods which are known to contain the missing substance, which is called *Water Soluble B*.

From the time of the recent discovery of the vitamins up to two years ago only one other vitamin was recognised. It was called *Fat Soluble A*, because it was generally found associated with the fats of natural foods, and two functions were linked with it. Thus, if laboratory-bred rats or young puppies are fed upon a complete food supply (complete, that is, from the point of view of quantity of proteins, fats, carbohydrates, and salts), which has, however, been chemically treated so that all the fat soluble vitamin A has been removed, growth does not take place and the calcification of the bones is deficient. The latter disease is *Rickets*. The addition of an extremely small quantity of fresh milk, cod-liver oil, or fresh butter corrects the deficiency.

Very recently indeed vitamin A has been shown to be a mixture of three vitamins, and we now have A, which is necessary for growth; D, the absence of which causes rickets; and E, which appears to be necessary in order that Reproduction may take place.

The extraordinary importance of these discoveries to the welfare of man must be obvious at once. Vitamins appear to be very delicate substances; they are easily destroyed and are associated intimately with fresh food substances. Thus, cooking, tinning, and all sorts of treatments so common to-day result in their loss. Many foods, like margarine and preserved milk, may be quite suitable if the deficiency is recognised and made up by the addition of small quantities of substances containing vitamins.

So much on the subject of food. Now a few words on food capture and the inter-relationships of plants and animals. It has been well said that life is summed up in the conjugation of the French verb *manger*—the pleasant active voice (except for the dyspeptic!) and its awful alternative, the passive. In general the total population of any region of the earth is a direct reflection of the balance between *je mange*, etc., and *je suis mangé*, etc.

The green plants must be the ultimate link in the food chain, seeing that they are the only creatures capable of converting raw materials into organic foodstuffs. Thus, where conditions favour their luxuriant development, we may expect to find abundance of life. The tropical forests of those lands favoured with the combination of heat, light, and moisture are simply seething masses of living substance. On the land the limits are set by drought and cold. In the sea the limit is set by the absence of light in the great depths; but whilst life may be sparse there, it is not absent, for small quantities of organic matter may fall from other levels. The most abundant region of the sea is the shallow zone round the land where the seaweeds abound, and the shallower seas. But the open sea, contrary to general belief, is quite well provided with the producers (green plants) as well as the consumers. One has only to dodge the bathers on an Atlantic liner and tip the bath-room steward to allow the bath water (sea water) to run through a bag of fine silk to discover this. The silk will filter out a mass of microscopic organisms, and the application of a powerful microscope to the deposit is startling. Here are all manner of the most beautiful creatures, some animal in their habits, others characteristic plants. Amongst the latter are diatoms, single-celled green plants. This floating life of the sea is called *Plankton.* It is also found in rivers, ponds, and lakes. The organisms composing it are, on the whole, microscopic, but its quantity must not be underestimated. In our home seas the greater abundance of plankton is usually responsible for the waters being green. At odd times in places the sea may actually bear a red scum owing to the abnormal development of some red planktonic organism.

The productivity of the Baltic Sea in plankton has been actually calculated and compared with land pastures; it is, of course, comparable in function and in composition. Hensen estimated that in terms of dry organic substance the yield in plankton of a given area was equal to five-sixths of the yield of that area of cultivated land. This may seem surprising at first, but then it must be remembered that production upon land is restricted to its surface; in the shallow seas an abundant plankton may exist down to the very bottom.

Most of the larger sea animals feed upon smaller fishes, molluscs, and crustacea, etc.; the cod, for example, feeds on small plaice, which feed, in turn, on small mollusca and crustacea; the porpoises feed upon herring and other fishes; others like the herring, and even very much bigger creatures like some of the whales, feed upon plankton and have a special apparatus for filtering it (sifting it) out of the water. Twenty millions of microscopic planktonic organisms have been estimated in the stomach of a sardine! One meets with all kinds of food habits in the same group. The oyster depends upon the microscopic life which it filters from the water and wafts into its shell; the whelk crawls about in search of decaying animal matter, whilst a relative of both, the cuttle-fish, actively grapples with quite large crabs, pins them down, and sucks out their contents.

The sponge sets up a million little currents through the pores of its walls and filters out the smallest living creatures of the waters, all of them invisible to the naked eye. The worms of the seashore live on what they can obtain from amidst the particles of sand or mud they pass through their bodies. Their number on a beach is roughly an estimate of the organic débris in the sand.

On land one meets the same infinitude of feeding habits, and one might fill volumes with descriptions of great diversity. Every niche appears filled. Insects devour the leaves, the roots, the stems, and the seeds of plants. They chew their hard parts and suck their juices. Even dead and dried timber is not free from them, and what the white ants can do on a tremendous scale in Australia, Africa, India, and other tropical countries, the death-watch beetle emulates in this country. All our foodstuffs have their particular pests, and even our luxuries, like cigars and tobacco.

Some creatures are extremely restricted in regard to food supplies—the honey-bee, for example, to the nectar and pollen of flowers. This, however, is mild restriction compared with those insects which attack and suck the juices of one particular kind of plant. Contrasted with this is the cockroach, which will enjoy anything from old newspapers to beer. There are birds which live on fruit and seeds, others which require and capture an incredible number of small insects, others which show remarkable skill in picking out worms, and, finally, the great vultures with their beastly habits of feeding on flesh. Many bats live on insects which they catch on the wing at dusk, others live on fruit (and are another of Australia's economic problems), and a few suck blood.

There is no point in going further, except to emphasise the fact that in all these diverse cases structure goes with habit, and one finds the most remarkable apparatus for food capture and its digestion.

Is it surprising to find that there is a host of animals which have adopted the plan of living in or upon other animals as parasites? There are undoubted advantages in this mode of life—the parasite is provided with shelter and surrounded with an abundant food supply. It has no strenuous search, nor does it enter into the perils generally associated with food capture. It is not remarkable that parasitic animals bear the characters of what we call degeneration—loss or poor development of the organs subserving the senses and the organs of locomotion. On the other hand, there are risks in parasitism. A parasite specially adapted to live on some particular kind of animal must make provision for its progency to reach this particular host in their turn. The risks involved in this are so great that we find parasites have remarkable powers of reproduction. The parasite itself must not (unless only a partial, temporary parasite) lose hold of its host, and both its food thefts and its production of poisonous excretions must be so nicely balanced that they do not kill the host, a result certainly equivalent to killing the goose that laid the golden eggs. It is very doubtful, therefore, if we can apply the term "degeneration" to such a nice degree of adaptation simply because in our eyes there is a loss of certain qualities.

Parasites may be external (ectoparasites) or internal (endoparasites). The former, of which the louse may be taken as an example, are not nearly so specialised as the latter, an excellent illustration of which is the tapeworm.

Now, one must not jump to the conclusion that, wherever two organisms live in this very close association, one is a parasite upon the other. *Parasitism* in biology means essentially living upon another organism's activity, stealing the results of its labours, and giving nothing in return, often, indeed, causing disease, if not death. There are, however, strange partnerships in the animal and plant world (it cannot yet be claimed that we understand many of them) in which there may be mutual assistance, or one organism may benefit without the other being harmed. The terms *Symbiosis* and *Commensalism* have been applied to such cases, both of them so loosely that it is now difficult to define them. The first may be applied to extremely intimate relationships, the most famous of which is the *Lichen* of the plant world. Here, indeed, the relationship is so close that we speak of lichens as if they were one particular kind of plant, just as they were supposed to be years ago. Now we know, however, that a lichen is in reality an association of two lowly plants—an alga and a fungus. Each is essential to the other.

The common green hydra of fresh-water ponds is green because of minute green plants living inside some of the animal cells. It is supposed that the animal supplies the nitrogen, which is waste, whilst the plant cells produce useful supplies of oxygen and carbohydrates, the result of photosynthesis. Probably many of the tropical corals feed entirely in this way.

Now let us return to parasitism for a moment. The parasites which have come in for most attention during the last fifty years have been those responsible for disease in man and in his domestic animals and plants. There is unlimited versatility in this parasitism, for we find that all kinds of animal and plant groups have some members which have developed parasitic habits. The most important human parasites are the *bacteria,* a few *fungi,* certain of the *protozoa* (causing sleeping sickness, malaria, etc.), and a number of different kinds of *worms* and *arthropods.* There are cases where parasitism seems to have no deleterious effect on the host. Unfortunately these cases are extremely rare. Usually there is some ill effect; occasionally it is very serious. There is, however, no mild acceptance of the parasite which thrusts itself upon the host, but frequently a reaction, and where resistance culminates in victory an *immunity* may be acquired by the host to further attacks from the same parasite.

CHAPTER III

PLANT AND ANIMAL TRANSPORT SYSTEMS—RESPIRATION

No organ in the body of an animal has captured man's fancy more than the heart. Pulsating day and night with its average beat of 75 times to the minute, about 39,420,000 in a year, its rhythmical beat has been accepted as the indicator of life, and, long before its true function was known, it was made the seat of the soul.

There are animals without hearts and without that system of tubes, the arteries and veins, which lead out of and into that organ. In the single-celled animals, and also in the lower multicellular animals, like the sponges, anemones, and even some of the "worms," food substances which have been captured and digested can, one might say, "ooze" through the body. Once, however, the animal becomes more highly organised and specialised, a transport system becomes necessary. Heart and bloodvessels appear, although in the "lower" animals the system is very simple compared with that of, say, man. In plants a transport system is also necessary. The roots absorb certain raw materials and water, the leaves take in carbon dioxide and oxygen. These substances must be brought together and the products of their combination shifted about hither and thither, to be used here, stored there, or thrown out elsewhere. Man with all his ingenuity has not yet explained quite satisfactorily the mechanics of water movements in the passages of plants. Evaporation at the leaf surface and root pressures (the result of the living root cells taking in water from the soil) are insufficient to account for water reaching the tops of high trees, and we must look to the combination of these forces with the activity of the living cells of the plant for the power to lift tons of water per year (not an excessive estimate for a large tree). Compared with this, the animal mechanism is understood, although its regulation is complex. Not only does the human heart alter its beat rate to meet the varying demands of the living cells for food, oxygen and waste removal in rest and work, health and disease, but it is affected even by the emotions—love, fear, pleasure, or a stirring tale. And not only does its beat rate change, but its capacity may change, too, so that the volume of the contents forced through in a minute may be greatly altered.

Let us consider for a moment one or two muscle cells in the leg muscles of a man walking. Work is being done, and this is always impossible without a supply of energy. The living muscle cells require a circulatory stream for several reasons: (1) Being far removed from the regions specialised for the absorption of digested food, they require food material:

(*a*) to repair waste; (*b*) to be used as a source of energy. (2) They require oxygen, for oxidations enter into the processes involving release of energy. (3) Waste substances must be removed, otherwise the machine would soon be clogged. Now, wherever substances have to be picked up or set down the bloodvessels break up into finer and finer branches until a network of most delicate tubules is formed (called capillaries), through whose thin walls certain constituents of the blood can pass. It is difficult to find an analogy in everyday life, because although we convey gas or water through large mains from village to village, through smaller pipes in the streets and still smaller in the house mains, and so on, the gas or water eventually leaves the pipes through holes which terminate the system. Such is not the case in the higher animals. The vascular network is complete. Large vessels (arteries) with thick impervious walls leave the heart, and these branch and rèbranch into smaller and smaller arteries until eventually networks of delicate capillaries are produced; but from these networks small veins are formed which join up with their fellows to form larger veins, and these again may join up with others until the largest veins are reached which enter the heart. Anything leaving or entering the system must pass through the walls of the bloodvessels where they are adapted for that purpose (the capillaries). In addition the capillary network provides a mechanism for extending the area of blood in contact with the tissues.

A pump and a system of tubes to all parts of an animal would be a very rigid device unless there were means of regulating the flow. An organ requiring a large circulation of blood must have large vessels, and the demand must vary according to the work being performed. There are occasions when the bloodvessels of the stomach and intestines should be well filled, others when the muscles require all the blood they can get. The mechanism is simple and efficient. The walls of the vessels, even of the capillaries, are contractile, and the lumen may be constricted. This at once cuts down the flow. The regulating mechanism is very sensitive, as will be obvious when it is pointed out that a blush is due to relaxation of the superficial skin capillaries of the face and pallor, due to cold or fear, is consequent upon their constriction.

So, by constricting here, relaxing there, and varying the intensity of action of the heart, the circulating fluids arrive where required in suitable quantity.

The blood system is not so complete as this in many invertebrate animals.

If food storage is required in the animal body, and this is more or less universal, for there are always bad seasons to be faced or strenuous periods—emergencies of activity—to be met, the soluble sugars of the circulating fluids are converted into insoluble compounds, and here there is a striking point of resemblance between animals and plants. In plants foodstuffs are transported as sugar and stored as starch; enzymes are present to facilitate the change wherever required. In animals the starch is Glycogen. Fats are also store substances. Proteins are less frequently found as stores, at least in animals.

Now let us turn to a function—*Respiration*—which is so characteristic of living things that evidence of its existence in man is taken with the heart beat as a sign of life. Modern discovery, as well as modern habits of life, have attracted considerable attention to the phenomenon of respiration. The athlete, the flying man, the mountaineer, and the diver have all been concerned in its investigation.

The general idea is that respiration—*i.e.*, breathing in the case of man—means the mere intake of oxygen and the output of carbon dioxide. Actually respiration is the complete passage of oxygen *to all* *parts of the body* of an animal or plant, and the output of some of the products of combustion—viz., carbon dioxide and water, which happen as a rule to take the same road. It is often assumed that respiration is analogous to the burning of coal in a furnace, and that any production of energy demands its presence. The idea is founded on the fact that most living cells are continually using oxygen, and that where increased activity takes place there are greater demands for oxygen and more carbon dioxide is produced. Actually muscle contraction is due to chemical changes *which do not require oxygen at all.* Oxygen is required *after* the contraction, during the period of relaxation of the muscle when certain substances are being removed.

Living cells can often support absence of oxygen for a little time. Still the fact remains that oxygen and oxidation are essential, except in a few cases, and respiration remains one of the most characteristic phenomena of life. The point of modern discovery is that it is not "the prime mover in the life processes, but an accessory which enables them to continue. Its utilisation provides energy which, so to speak, winds up the machine for a new run."

Plants and animals living submerged in a fluid medium (sea, pond, river, or aquarium tank) obtain their oxygen from supplies dissolved in the water, except in the case of animals which come to the surface for air. Other creatures depend upon the air for their oxygen supplies directly. Single-celled organisms and the more simple animals absorb oxygen through the general surface of the body. Increase in size and complexity, with many cells packed close together often accompanied by the presence of a somewhat impervious outer coat, hinders this and renders a special region necessary for oxygen intake. Such regions are the *Respiratory Organs,* which are structures where the internal fluids of the body can be brought into very close contact with the outer medium. They are likely to be rather delicate; the respiratory surfaces will be certainly delicate and of necessity kept moist. They are most frequently greatly folded extensions of the outer surface, and one finds that whilst they project outwards in aquatic animals (where they are termed gills), in land animals they are tucked in (lungs and other organs). The efficient area which may be developed in a confined space is surprising. It may be illustrated by the fact that the area of the human lung surface active in respiration is somewhere near 1,000 square feet. The tiny leaflets of a fish's gills are present for the same purposes; they cannot present their area to the outer oxygen-containing medium unless freely separated from each other. Taking a fish out of water generally results in asphyxiation, because, whilst actually brought into contact with a greater oxygen supply, the gill leaflets, not being supported, lie on top of each other and the respiratory surface is greatly reduced. Some method must be found for changing the medium surrounding or within a respiratory organ. Thus gills are waved about, or are extended in water currents, or there are special movements for setting up currents over them. For the same reason all animals with lungs have breathing movements by which these bags are rhythmically emptied and filled.

All this leads to a consideration of the circulating fluid which carries the oxygen. In some of the invertebrate animals the blood appears but little different from the sea water, and can only carry as much oxygen as can be dissolved in water. In others (many of the worms, cuttle-fishes, crabs, lobsters, etc.) and more particularly in the vertebrate animals the blood is much more efficient as an oxygen carrier by reason of the presence of chemical substances specially suited for this purpose. The best known and by far the most important of these are *Hæmocyanin* (in cuttle-fishes, crabs, lobsters, and many other molluscs and crustacea) and *Hæmoglobin* (in vertebrates). The first named is a protein combined with copper and is blue, the latter is a protein combined with iron and is red. Thus the colour of the blood is due to a substance which is in the highest degree important in respiration. The value of hæmoglobin depends upon its peculiar property of combining under certain conditions with oxygen forming oxyhæmoglobin (bright red in colour), and yet being capable of giving up all this oxygen again (oxygen dissociation) under other conditions. This see-saw can go on indefinitely. Combination with oxygen takes place where free oxygen is present, and depends upon its pressure and upon five other variable conditions (amongst which the carbon dioxide present and the degree of alkalinity or acidity of the blood may be noted). This sounds rather complex, and it certainly is. Put in a nutshell, however, it means that blood containing hæmoglobin will take up a considerable quantity of oxygen when flowing through the capillaries of a respiratory organ and with equal facility will give that oxygen up again when in contact with the living tissues which are requiring it.

We may now try to apply these fundamental features of respiration to the practical side, and here we must stress human problems.

A man is resting, reading a book on a couch. His breathing is slow and regular, and he is practically unconscious of it. His heart is beating 70 to the minute withdrawing blood from the veins and pumping it out into the arteries. At every beat 70 cubic centimetres of blood are pumped out, say 8¾ pints per minute. The man gets up and proceeds to walk; his pulse rate automatically increases and so does his breathing. He runs and runs hard, and his heart beat increases until it may reach 150 per minute. At the same time the blood output from the heart *at each* *beat* increases, say 120 c.c. is reached. The heart is now pumping almost 4 gallons per minute! This automatic increase is to meet the increased demands of the living cells, chiefly the muscles which are involved in the work done, to bring them oxygen and to carry away the waste products of oxidation. The flow of blood through the lungs has increased to such a point that the lungs must be emptied and filled with air far more rapidly in order to provide a sufficiency of oxygen. Our runner now stops, but his heart beat still continues to be rapid and the panting for breath goes on for some minutes, only gradually slowing down.

What caused the heart and chest movements to increase in speed as muscular exercise commenced? Why did not both fall to the resting condition immediately the man stopped running?

The explanation so far as we know at present is the following: With each contraction of the muscle fibres chemical products appeared (lactic acid amongst others) which had to be oxidised. One result of this oxidation was the production of carbon dioxide. The presence of lactic acid in the blood, as also of carbon dioxide in the smallest of the lung chambers and in the blood, was a stimulus to the mechanism (the nervous system) occasioning increased heart beat and chest movements.* We now see why these were automatic and out of the control of the will. But having reached a certain point, the respiratory exchange was still insufficient to meet the enormous demands made by the athlete's greatest effort. This did not prevent his continuing. He obtained his energy by the breaking up of carbohydrates in the muscle and the lactic acid accumulated since there was insufficient oxygen to oxidise it. Hence, although he stopped running, the panting for breath continued; the man had incurred an oxygen debt, and respiratory activity continued higher than normal until once again the constitution of the blood and tissues became normal.

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* Probably much still remains to be discovered regarding this regulation.

Curious respiratory problems are involved when a diver descends in one of the ordinary rubber diving dresses. In order to counteract the pressure of the water on the dress, the air received by the diver must be under a like pressure. The composition of the air in the helmet will, however, depend upon the *rate* of supply, and the respiratory activity of the man. Suppose that the result is the production of 2 per cent. carbon dioxide in the air of the helmet. The effect of this will vary according to the depth. At twenty-two fathoms it would really be equal to five times that percentage at the surface and would exert the same influence as that amount; it would *stimulate* the respiratory regulating mechanism to greater and greater efforts and the man would pant for breath. Yet there would be actually no lack of oxygen; on the other hand, this, too, would be at far higher pressure than at the surface. Serious danger would, of course, result. The remedy is to increase the *rate* of air pumped down as the pressure increases, so that the carbon dioxide is more quickly removed. Conversely to the above, a flyer ascending in an aeroplane passes into regions where the air pressure is reduced; there is less air each time he fills his lungs, less oxygen, and *less carbon dioxide*. He should therefore breathe more rapidly in order to obtain a sufficiency of oxygen. Instead, the lack of carbon dioxide actually tends to reduce the breathing rate. Thus the surprising feature that the man suffers from lack of oxygen, without at first realising it, because the breathing rate is unaffected. With continual reduction in air pressure the conditions again change; events then become more dramatic!

These two respiratory examples show how beautifully regulated is the animal mechanism and the effect of abnormal conditions in putting it out of gear.

The respiration and oxygen consumption of different animals is as variable as is their organisation and activity. There is indeed little resemblance to the often quoted analogy with a fire. Give a burning candle more oxygen and the rate of combustion increases; reduce the quantity and combustion decreases. As a general rule, for the higher animals at all events, if the supply of oxygen is increased the rate of combustion in the body does not vary. The same applies to reduction unless the point is reached where a further drop renders the oxygen supply insufficient for the animal's requirements.

There are always interesting exceptions in biology, and so far as respiration is concerned these are supplied by creatures which do not require oxygen at all; indeed some of them are hindered by its presence. They are called *Anaerobic* organisms. Some extreme examples are found amongst the bacteria, and one of these is the bacillus of tetanus (lockjaw). To grow a culture of this germ, which is found in well-manured soil, one must cover the culture fluid with oil to keep the air away or pass some gas like hydrogen into the culture flask to drive out the air.

Parasites of such high organisation as the tapeworms, which live in the intestines, are also anaerobic.

If we consider the case of the muscle cells already quoted, we shall realise that there is not an absolute difference between the anaerobes and the aerobes. In both cases energy is set free by the breaking down of complex substances — proteins to amino-acids, starches to sugars, sugar to acetic acid, sugar to alcohol, and many other types. This, however, in aerobic organisms provides only a small amount of energy compared with that set free by oxidation.

Completely anaerobic organisms have to do without the latter.

Let us now sum up the position we have reached in regard to the mechanism of living organisms. The activities of protoplasm, which we may regard as a complex of systems, require the constant supply of certain chemical substances—proteins, carbohydrates, fats, mineral salts, and water. Green plant cells alone can manufacture the proteins, carbohydrates and fats from simple substances (carbon dioxide, water and mineral substances), but special energy is required for this and is obtained from the sun in the form of radiant energy. Energy is required, however, for the constant change, which is the characteristic feature of living protoplasm (also for growth, and particularly in animal cells, for movement and heat production). This is obtained wholly, or more generally in part, by the splitting of the complex substances enumerated above. In the majority of cases the substances so produced are oxidised to carbon dioxide, water, etc., with another release of energy, and waste substances are produced. On the green plant side the latter are mainly the products of oxidation of carbohydrates and fats. On the animal side waste nitrogenous products play a much greater part, and so we find excretory organs specialised for their removal. If the protoplasm is in direct contact with a medium capable of supplying all the above needs directly, a relatively simple organisation suffices. With aggregation of cells to form larger organisms it is necessary to carry substances to and from the cells which are out of contact with the external medium. This occasions the development in the multicellular animals of a respiratory system, a circulatory system, and a heart. The multicellular plant in the same way develops a conducting system, rootlets for the absorption of mineral salts in solution, and leaves for the absorption of carbon dioxide.

And now for a final statement which is the corollary of the above. Animal life is characterised by great energy output and the breaking down of complex chemical substances which release this energy. On the other hand, the fundamental characteristic of the green plants is that they produce these compounds of greater energy, the energy required for this being obtained from the sun. This transference of radiant energy into chemical energy and its storage in plant matter is essential for the existence of the higher forms of animal life, and during the last generation has been at the bottom of man's industrial development (the coal age).

CHAPTER IV

MOVEMENT AND ITS CORRELATED FEATURES

From ancient times movement has been associated with life, and even to-day the two words are often made synonymous. The power of locomotion, which is one expression of this property of protoplasm, is, however, the exception amongst adult plants whilst characteristic of animals except for a few types which live firmly fixed to some substratum (sponges, corals, zoophytes, barnacles, etc.). The actual shape of living creatures is closely associated with locomotion. The shape of a fish like the mackerel is admirably adapted to rapid movement through water; one could not conceive of a starfish performing like movements. One may assume, in fact, that the presence of bilateral symmetry—right and left sides, a top side and a bottom side—was developed in connection with progression in one particular direction. Where radial symmetry occurs in the animal world, it is found amongst attached or floating animals. And if one end of an animal is always foremost in progression, what would be more likely than to find that that end, always coming into contact with the environment first, should be most sensitive? In fact, amongst multicellular animals movement in this way is almost always associated with some sort of a "head."

Movement in the higher plants is limited to the movement of parts, to the circulation of fluids and protoplasmic movements in the cells. The former can, however, on occasions, be rapid enough to be very obvious, as, for example, the collapse of the leaves of the sensitive Mimosa on being touched. Many single-celled plants can swim actively, and frequently certain plant cells, the sex cells which are set free, are just as mobile as those of animals.

Locomotory movements in animals are achieved (*a*) by a flowing movement of the protoplasm, (*b*) by the lashing movement of extraordinarily fine processes from living cells, and (*c*) by the contraction of fibrils of specialised protoplasm. A muscle cell presents the greatest development of this fibrillar structure. The first method is confined to unicellular organisms. The second type (movement by cilia or flagella) is also most frequently found amongst the single-celled organisms, but there are higher animals whose locomotory movements are due to a covering of cilia, and still more frequently their early stages move by this means. Both these locomotory mechanisms require a watery fluid, and so they are confined to creatures living in water or to parasites within body fluids.

The third type of movement is at once the most important and the most fascinating. The majestic flight of the albatross, the graceful pirouette of the ballet-dancer and the gorgeous sound of a Beethoven symphony are all produced by muscle movements!

The occurrence of delicate fibrillæ in the protoplasm of the single-celled creatures may be regarded as the first indication of muscle. In the animal group, to which the jelly-fishes belong, there are cells in which the fibril development is much more advanced, and one can speak for the first time of muscle cells. They tend to grow exceedingly in length until they become fibre-like. A large limb muscle, such as the human biceps, is made up of bundles of muscle fibres, and each fibre consists of several cells. The contractile matter in this case is likewise found in the delicate fibrillæ.

The wonderful feature of the fibrils is not that they can contract in length as the result of a stimulus, but that alternate contraction and relaxation is possible, and that such alternations may reach the extraordinary velocity of 250-300 per second. This is the case in the muscles which move an insect's wing during flight. The muscle fibre does not contract essentially in volume when it becomes shorter. Every boy knows that the contraction of the biceps muscle when the arm is bent at the elbow is accompanied by an increase in its girth.

What sets the fibre contracting? What goes on inside the fibre when it contracts? Where does the power come from? In the lowest forms where muscle fibrillæ are first developed contraction may result from many different sorts of stimuli, affecting the cell containing them. The contraction of the muscles of higher animals is normally brought about by nerve impulses conducted to them by nerve fibres, but in a muscle nerve preparation (muscle and its nerve taken immediately from a frog which has been killed) various kinds of stimuli—electrical, chemical, mechanical—may produce contraction if applied to the nerve or the muscle direct.

Compared with our mechanical instruments for doing work, the muscle is very efficient indeed. Its efficiency has been calculated as 25 per cent. against 20 per cent. for an efficient engine. Early experiments showed that any increase in muscle activity was accompanied by greater respiratory exchange; oxygen was used and carbon dioxide produced. Hence the assumption that energy for muscular *contraction* was obtained by the combustion of muscle substance. Now, combustion in everyday life is usually accompanied by heat. It has been possible by the invention of extremely delicate electric methods for the determination of heat production to find the amount produced by a muscle fibre at every stage from stimulation to relaxation. Application of these methods shows that the initial heat production which takes place when a muscle fibre begins to contract occurs even though oxygen be absent altogether. It is, in fact, associated with energy production by "breaking-down" chemical changes; oxygen is quite unnecessary, and not a party to these at all. The story of muscle chemistry may be suggested as follows. The muscle before contraction contains practically no lactic acids; its cells are consuming but little oxygen (merely the amount necessary to sustain the normal processes going on in the protoplasm). A nerve impulse comes, the muscle contracts, heat is produced, various chemical changes occur, and lactic acid appears. Then oxygen is required, the lactic acid is oxidised, and carbon dioxide is produced as a result. But what is the material whose breakdown gave us the lactic acid? Experiments seem to show that it is carbohydrate. Here we must leave the subject, you will say just having reached the most intriguing point. That is true. The knowledge that glycogen or sugar carried to the muscles by the circulation is the substance whose breakdown provides the energy for muscle contraction does not explain how a muscle fibre shortens. The exact mechanism by which the chemical energy is converted into the mechanical energy of shortening is still awaiting discovery. We do realise, however, why a muscle contracts without oxygen, and why oxygen is necessary before it can contract again. We can understand better why the athlete's effort soon has to come to an end, although he can run again after a period of rest. He has, in fact, accumulated such an amount of lactic acid that further muscle activity is hindered until it is oxidised away.

In order that muscles may exert their power to the best advantage in the production of definite movements, they must be definitely arranged in the body, and for the greatest efficiency a firm attachment is usual. They are brought into relationship with skeletons, which serve not only to support what would otherwise be shapeless masses of living tissue and to protect delicate organs, but provide the muscle attachments and levers, the jointed framework upon which the direction of muscle pull may depend.

In a few cases muscle pull is against fluid or an elastic ligament. More generally one finds one muscle pulling against another. Contraction of one is simultaneous with relaxation of the other.

Where parts of plants move, the mechanism is rather different from muscle movement, and is due to tissues contracting or stretching owing to changes in the amount of water in the cells, which may be turgid or flaccid. The very active movements of the sensitive plant and the morning and evening movements of certain leaves and flowers are due to such variations. More rapid movements still may be due to cells exploding as the result of water absorption.

It might seem rather unnecessary to devote even a line to the reasons for animal locomotion. Whether it is a matter of instinct or intelligence, one would assume that animals moved so that their environment remained most satisfactory from all points of view. Some of these locomotory habits are, however, more than usually interesting, especially the migrations which appear associated with reproduction. The migration of birds is the most familiar of these, and stories of the extraordinary 2,000-mile flights from the northern to the southern hemisphere are amongst the most intriguing features of natural history. The birds nest and produce young in one district and live in the other during the non-breeding season. Generally the nesting district is in a colder climate, and the winter season there may be too difficult for the birds. The big puzzle is—how do the birds find their way? To make it more difficult it may be added that the young birds who have never made the journey before fly back without the company of the older birds and parents.

This is only one of a number of similar migrations equally startling. The eels of European rivers pass out into the sea (a change of water which would kill most fresh water animals) and swim hundreds or thousands of miles, until away in West Atlantic waters they breed and probably perish. That is wonderful, but still more astonishing is the fact that their delicate larvæ (early stages) make the journey back, and eventually enter the rivers of Europe. How do they find their way? What is the guiding principle? It is much more difficult to conceive of a mechanism in the case of a slow-moving creature, taking months to cover the distance, than in the bird examples where rapid flight reduces the journey to hours or days, and the environment changes quickly. Many other fish in the sea and smaller creatures with poorer powers of locomotion move from one type of marine environment to another at the breeding season. All the examples provide the same puzzle.

The force a muscle can exert is probably chiefly dependent upon the number of muscle fibrils in the muscle, and thus upon the sectional area of the muscle. This is worth keeping in mind, for it will help us to understand some of the remarkable tales about the enormous power of certain animals. A flea, for example, can jump six or eight inches (no, my friend, I don't believe yours went further). Since a flea may only weigh $\frac{1}{78000}$ ounce, it is not surprising that people have calculated that a man equally powerful could leap 36,800 miles! There is a "catch" in the example. It would be true to say that a man with the same power to weight ratio would have very much greater powers of leaping than he has at present, but in order to have this power each one of his muscle fibres would need to be many times more efficient than those of the flea. The reason for any very small creature's feats of strength is that with simple increase in size the volume and weight increases as the cube of the linear dimensions whilst the sectional area of the parts only increases as the square.

CHAPTER V

SENSITIVITY AND REGULATION

OUT in the back blocks of Australia I once saw a Chinese cook neatly chop off the head of a hen that was ultimately to grace my dinner-table. To my horror the headless animal ran almost perfectly about 20 feet before collapsing. That movement involved the harmonious action of a large number of muscles. What controlled them and what set them in motion?

It is said that a bat, if confined in an absolutely dark room across which wires are stretched, will fly round without touching any of them. How are they perceived? A clever sight reader sits down at a piano with a new piece of music. How are the black marks on the piece of paper translated so rapidly into finger movements and possibly beautiful sounds?

If a little gunpowder is spread out to cover, say, an area of two or three square feet, and a lighted match is brought into contact with it at one point, a rapid change, accompanied by flame and smoke, would pass from that point throughout the mass. It would not be simultaneous, a fact which might be more clearly brought out by laying a long trail of gunpowder and noting the time it took for the flame to pass along it. Striking the gunpowder with a hammer at one end might produce the same effect. We can speak of this reaction to flame and shock as sensitivity. Some very unstable chemical compounds—chloride of nitrogen, for example—are much more sensitive than gunpowder.

It is very characteristic of living protoplasm that it is sensitive to change in its environment, and mere contact, a chemical or a physical change (temperature, electricity), may set up some complex readjustments which pass in the form of an impulse throughout the mass. If the stimulus is very great, a large and irreversible change may take place in the protoplasm, bringing disorganisation and death. (This might be compared with the change in the gunpowder.)

The life of any mass of protoplasm, small or large, is the epitome of its sensitive readjustments to all kinds of changes taking place about it.

Now, if we want to make sure of an explosive being set into action by a small force delivered at one particular spot, it is customary to use some particularly sensitive and violent reacting substance in the form of a detonator. In an analogous manner one finds specialisations of protoplasm, either in a cell, or more frequently a whole cell, which are particularly sensitive. This development goes, however, much further than anything in our analogy, for the protoplasm can become so adjusted that it is only influenced by one kind of stimulus. Here one finds protoplasm sensitive to light, in another place sensitive to substances in solution. We speak of these regions in the higher animals as the *Sense Organs*. They become the intermediaries between the organism and the external world, especially where the sensitivity of other surfaces of the body may be reduced (as, for example, where covered with some protective armour). It must not be forgotten that in the higher animals, where special sensory cells are developed, the protoplasm of other cells not directly stimulated often retains something of its fundamental property.

The highly developed sensitivity of the protoplasm of sensory cells is startling. One might stress as an example the wonderful efficiency of the eye; instead, let us remind the reader of a simple organ, the nose, which scarcely seems to reach in man the efficiency attained in lower animals. Yet it is possible for the human nose to recognise the presence of $\frac{1}{460,000,000}$ of a milligram of mercaptan in 50 c.c. of air! It is doubtful whether the chemical analyst with all his delicate apparatus can beat this.

One cannot discuss the sensitivity of animals and plants without bringing in the extraordinary mechanisms of regulation exhibited by them. In fact, it is the manifestations of the co-ordinating systems which have always favoured the belief that a living creature is something more than a machine driven by physico-chemical forces. In the simplest organisms we have seen that the protoplasm may be easily affected by external stimuli, so that some change takes place in its ordered systems. This change passes through the protoplasm (*cf.* our analogy of the gunpowder). From this fundamental property of protoplasm one of the higher systems of regulation has been evolved. The passage of an impulse through the protoplasm of all sorts of cells in a multicellular animal organism would probably be slow; it would certainly be too diffuse. Contact of, say, the middle of the back with a red-hot poker suggests *immediate* and properly regulated action on the part of the arm and leg muscles! Quick response is enabled by chains of specialised cells, which form definite paths along which an impulse passes quickly. The cells are *Nerve Cells*, and they make up a more or less complex *Nervous System*. The nature of the change in the protoplasm of nerves, which travels like a flame along a train of gunpowder or the electric current along a wire, remains to be discovered. The impulse runs moderately fast—four miles per minute—but *nothing like so fast as an electric* current.

The beginnings of animal sense organs are seen in the protozoa, but there is no steady development as one proceeds through the animal series along any line that we may suppose evolution took. Though, perhaps, in the vertebrate animals we find their greatest efficiency, there are many exceptions. Wherever animals are most active and live most openly we find some sense organs well developed. Thus there are very active marine worms with eyes relatively as well developed as those of fishes; on the other hand, the earthworm has nothing but scattered sensory points in its skin, which enable it to distinguish light from darkness. The active cuttle-fish has well-developed eyes; its sedentary relative, the oyster, has none; the snail comes in between these two extremes. The frog has obvious eyes, whilst another amphibian—Proteus, of the caves of the Tyrol—has none at all. Internal parasites, notoriously deficient in sense organs, have neither to flee from enemies nor go in search of food. It is tempting to theorise on this. Did the activity and the greater needs bring forth the efficiency of protoplasmic receptors in animals whose habits seem to require them, or was it the other way about? Can we find evidence that the active habits are the result of a more perfect "awareness"? The relatives of many parasitic animals are well favoured with sensory structures and would indicate that loss of these occurred with the adoption of parasitism. Even this might be interpreted the other way round, however, and there is quite a difference of opinion as to whether cave animals lost their eyesight as the result of living in darkness, or whether they were practically blind originally and found a refuge in dark places, where loss of eyesight was no disadvantage. These are the little problems that crop up when one thinks of animal evolution.

The first trace of what may be regarded as an eye appears in some of the single-celled creatures as a tiny spot of red pigment. Here there can be no question of seeing anything, but one may assume that the pigment, absorbing light, renders the protoplasm more than usually sensitive to it. More organised pigment masses are found in the cells of jelly-fishes. Next we find some means of focussing the light by means of a lens on to the pigment containing cells. This brings both direction and concentration of light rays with it. Finally, we have animals in which large numbers of specialised light receptor cells are aggregated together in a retinal layer and provided with lens and focussing arrangements, so that sharp images of the environment are thrown on to it. In the lowest cases vision is probably simply a matter of responding to light and shade. At the other extreme are the wonderful eyes of the cuttle-fish, of the insects, and of vertebrate animals. Their structures may vary exceedingly, but the mechanism remains very like the ordinary camera—a lens, a focussing arrangement, and a retina of specialised cells whose protoplasm is readily affected by radiant energy.

The other sense organs may be traced in similar ways, although, with the exception of the ear, it would be difficult to show such a long series of types and stages. The organs of taste consist of collections of cells in which the normal sensitivity of protoplasm to chemical substances in solution is greatly heightened. It may even be specialised, so that sensitivity to particular substances is greater than to others. The olfactory sense is difficult to separate from taste in aquatic animals, because the only medium touching the animal surface is water.

In everyday life it is usual to speak of five senses. The number is larger than five; one or two are not generally realised to exist, and others are confused under the sensation of "touch." The protoplasm of the unspecialised single-celled organism is sensitive to contact and to changes in temperature. In man, however, there are special sensory receptors in the skin for mere contact, for temperatures warmer than that of the skin, for temperatures lower than the skin, and for pain; and it is possible to map out these minute sense organs by touching the skin with a point (at normal temperature, or warmed or cooled, as the case may be). Senses not recognised by the public include one which is met right through the animal kingdom and is often associated with the entirely different sense of hearing. We refer to the sense of *Orientation.* It may be granted that, as a rule, human beings feel that they are in this or that position in regard to the earth about them by means of their eyes or by contact. There is, however, another organ which relates the body to change of position in space. In the crab and lobster it is a relatively simple bag. In man it is a system of three canals and associated parts connected with the ear. We cannot describe complex structures like these without pictures. We may say, however, that the organs of orientation generally consist of little particles of secreted substance or of sand grains from the outside world, balanced delicately in a chamber upon the hairlike processes of sense cells in the wall of the chamber. If the animal is turned upside down, the particles rest and press upon other sense cells, and this contact stimulus is the trigger.

Is it possible to find specialised sense organs and a nervous system in plants? Certainly there do not seem to be any very obvious structures for the reception of changes in the environment, like animal sense organs. Yet roots grow down, stems grow up and also towards light. Rootlets are attracted by and grow in the direction of moisture. Leaves and flowers perform diurnal movements, and so on. A fly caught on a leaf of Venus' Fly Trap causes the leaf to fold over it, and Mimosa, the sensitive plant, very quickly responds to touch. We often take all this for granted, until we see how a bean seedling, growing in damp sawdust in a box, will respond time and time again to our treatment if we take it up and place it with its root tip pointing upwards. It can easily be shown that for some reason or other the protoplasm of root tip and stem tip is sensitive to the force of gravity. The response is different, however, and one grows towards the pull, the other away from it.

It is generally believed by botanists that there is nothing resembling the animal nervous system in plants. Where a stimulus to one part is followed by the response of another part, it is assumed that as a result of the normal sensitivity of living protoplasm the part stimulated has either produced some chemical substances which are carried to the region of response or that a hydromechanical disturbance is set up. In the latter case a change in the turgidity of a cell affects its neighbour, and this affects the next one, and so on. We might almost liken it to the passage of a pulsation through a water-pipe filled with water. It should be noticed that the first-mentioned process, the translocation of a chemical substance, is found in animals too, and we shall describe it later.

Efforts have recently been made to show that the passage of a response in a plant is quite similar to that along an animal nervous system. At present, however, the botanical world appears to stand unconvinced.

We have seen that the rapid and harmonious response of parts of a multicellular animal to stimuli affecting some (possibly) distant part of the body is bound up with the presence of a special system of cells, the *Nervous System*. In man and other vertebrate animals, from the fishes upwards, the central nervous system is the brain and the spinal cord; in the invertebrate animals the central nervous system never has this form. Where highly developed, it most frequently takes the form of two masses of nerve cells and fibres in the head and two cords running the length of the body, but ventrally, not along the back as in vertebrates.

Such types of nervous system did not appear all at once in animal evolution, and some of the lower animals provide us with an inkling of the steps that might have been taken. Thus in the jelly-fishes and their allies there is no central nervous system as distinct from the peripheral system. All we have is a network of special cells under the superficial bounding cells of the body, and this network consists of nerve cells. The higher types may have arisen through the grouping together of nerve cells. Whatever may have been the history, the nervous system comes to consist of aggregations of cells, many of which have one or two exceedingly long processes, which pass out to relatively very distant parts of the body. A nerve is a collection of these long processes (nerve fibres), each of which is a path leading to some particular destination. It is a remarkable anticipation of man's modern scheme of telephone cables, in which the wires from very many houses are collected together in one thick cable and taken underground to a central station.

Perhaps the nearest thing we have to a nerve impulse is an electrical current running along a wire Let us take this analogy further. One of the most common and simple schemes in everyday life is an electric bell " circuit." We press a button, the current runs round a closed circuit and is translated into movement at an electric bell. The whole thing is as automatic as pressing the trigger of a loaded gun and setting forth on its journey a rifle bullet.

Now, it is quite conceivable that we might have a nerve circuit of a similar type. A contact—simple touch, chemical substance, or light ray—with a sensory cell might send an impulse along a definite path to terminate in a muscle fibre and cause contraction. The whole thing could be automatic, so that stimulus of the particular sense cell would be certainly followed by contraction of the muscle fibre. Two nerve cells at least would be required for the circuit—one the sensory cell with its long process, and a motor cell linked with it and with a process stretching along to the muscle fibre. This is our simplest nerve circuit, but it is probably only hypothetical. It is a valuable conception, however, and the type of activity at least is an actuality. We call it a *Reflex Action.* To be nearer the truth we must make the path a little more complex without changing the automatic nature of the response. We must bring the termination of the process of the sensory cell into contact with more than one motor cell. Most reflex actions would involve the stimulation of several sensory cells at once, and so a number of paths would be involved. The essential is that a circuit is traversed automatically by nerve impulses, and an involuntary action results as certainly as the electric bell rings when the outside push is pressed. Concrete cases are easy to find. A sudden movement made in front of the human eye causes a rapid, involuntary eye-blink. This is a reflex action.

Now, it is possible to make an extremely complicated machine in which many final movements follow certain initial actions. Pressing a button might set a newspaper printing machine in action, which not only prints, but folds and cuts the separate copies. The automatic telephone is another example. All we have to arrange in these cases is that one movement sets off another. Automatic controls might regulate the action.

Given such a type of activity in a living animal, we should regard its complete behaviour as the expression of a set of co-ordinated reactions. There would, of course, be no place for "learning" or "experience," any more than in our machine. To what extent can the activities of the multicellular organisms be interpreted along these lines? We might conceive of the responses of a jelly-fish being entirely automatic. The animal is carried hither and thither by currents in the sea. All it does itself is to keep floating by movements of its bell (like opening and closing an umbrella). These movements result from the rhythmic contraction of muscles which are connected up by nerve cells to little sense organs situated round the margin of the bell. If the jelly-fish is tilted by wavelets one way or another, or becomes turned upside down, the sense organs receive certain stimuli and impulses are passed to the muscles, which right matters. A submarine or aeroplane might be provided with a stabilising mechanism working very similarly.

Now, in the human being we have, added to this automatic and involuntary type of activity, consciousness, memory, and voluntary action. It is clear that certain cells of the nervous system are responsible for this advance, and it is equally clear that they are collected together in that part of the nervous system called the *Brain*.

It is beyond our bounds to pursue this matter further, except to indicate that involuntary and voluntary actions are closely associated. Two excellent examples are walking and riding a bicycle. Each activity is the result of hundreds of muscle movements all beautifully co-ordinated. One follows another, and one is possible only when another has taken place. *Both activities must be learned.* We sit on a bicycle, and this and that sense organ is brought into action. The brain builds up its conscious picture, and we painstakingly perform this and that voluntary movement

It is a matter of will. Then gradually the actions become automatic and involuntary until the day arrives when we can cycle along the street, balancing, steering, and moving forward, and at the same time thinking deeply of the holiday we are going to enjoy next summer or the hat we intend to buy next week. Cycling has become a machine-like series of reflex actions.

What has happened here to make involuntary reflex actions and automatism carry on what was impossible at first, and are we to regard the complex activities of the lower animals as unconscious co-ordinated reflex actions (like riding the bicycle automatically) or as involving consciousness and will? The first of these questions is much more easily answered than the second, and we may postulate that, with repetition of " messages " along the same paths, these become (like well-trodden paths through a wood) more readily traversed, until finally all the varied stimuli resulting from a seat on a bicycle automatically release impulses along the proper nerve fibres. It has been suggested that conscious processes of higher animals are associated with the activity of very many cells in the cortex of the brain. If such is the case, one would be justified in regarding the activities of the lower animals as built on reflex actions alone.

We must try to find a few lines to describe " remote control " (as our wireless enthusiasts call it) in the animal by the conduction of chemical substances from one part to another. Curiously enough, this method, which is put forward by the botanists as one of the possible explanations for passage of an impulse in plants, has only been fully appreciated in animals during the last twenty-five years. Possibly the ease with which the nervous system may be seen and dissected out in animals accounts for this.

The chemical substances, whose passage from one part to another is responsible for control or initiation of some activity, are found in internal secretions, and have been called *Hormones* (ὁρμάω—I excite). Probably every organ in the body, and possibly every cell, is connected chemically with the rest. In speaking of hormones, however, one thinks first of the examples where a definite secretion is very striking. These chemical messengers have so far only been demonstrated in the vertebrates where they are carried by the blood stream. Some of them are produced by organs which play other functions as well. The best known of these are the reproductive organs, which not only produce germ cells, but secrete into the blood substances which control the development of other characters of the body secondarily associated with sex. In man the presence of the reproductive organ hormones determines the change in the voice at puberty and the development of hair. The plumage of birds may be so changed by removal of the reproductive organs that a female bird may come to look exactly like the cock bird. The secretion of digestive juice by the pancreas is set going by the passage via the blood of secretin, which comes from the walls of the intestine and is itself produced by the arrival of partially digested foodstuffs from the stomach. The most interesting of all these secretions come from the *Ductless Glands*, such as the Thyroid, Pituitary, and Adrenal (or Suprarenal) Glands, etc. It seems almost certain that the temperament of different people is largely determined by the balance of the secretions of these glands. A very small amount indeed of Adrenalin, a hormone of the suprarenal, injected into the blood, causes a rise in blood pressure and quickening of the heart beat. The whole effect is to make the animal more ready for an emergency, ready to fight, or to make the speedy reactions characteristic of efficiency.

CHAPTER VI

REPRODUCTION—GROWTH—DEATH

The power of reproduction is one of the most peculiar as it is one of the most fundamental characters of living organisms. And whilst the puzzling problem of sex and the extraordinarily complicated paths by which in some cases reproduction is ensured may captivate us, nothing is more remarkable than the fact of reproduction itself. To realise its full significance one must remember that so far as one knows to-day, living protoplasm and living organisms never originate from non-living matter. The old belief that worms and maggots arose from decaying flesh is easy to refute. To show that there is no *Spontaneous Generation,* as it is called, of bacteria and other microscopic simple organisms is more difficult. Since, however, the brilliant work of Pasteur and Tyndall, no one has been able to show that living organisms arise in any other way than from previously living organisms. Moreover, an organism only gives rise to its own kind. A germ of tuberculosis has just as certainly come from a previously existing germ of tuberculosis as a kitten has come from a cat. Now, this absence of spontaneous generation is a remarkable fact, for it leaves us absolutely in the dark as to the origin of life and living matter. There must have been a time in the dim, remote past when physical conditions on this earth were such that no possible form of life could have existed. Was this followed by one definite period when the conditions were so peculiarly balanced that living matter originated? If that were not the case, either living matter is arising to-day from non-living (without our being aware of it), or else at one time life reached this earth from some other heavenly body. Each idea has had its supporters.

The simplest and apparently the most primitive kind of reproduction is that found amongst the single-celled plants and animals. A bacterium, for example, during its life of about twenty minutes or half an hour incorporates new material into protoplasm and grows. A point is soon reached, beyond which further increase of size is impossible. (A very good reason put forward to account for this is that, with growth, volume increases as radius^3, but the surface area only as radius^2. We have seen that all the exchanges between the organism and its environment take place through this surface, which is thus gradually becoming too small.) The bacterium then simply divides into two, and the two smaller individuals commence to grow in their turn and live their twenty minutes of life. This is reproduction by *Simple Fission*. It need not be binary; many unicellular creatures divide into many parts—*Multiple Fission*.

One finds reproduction by simple fission in a great many lower organisms, whilst a variation of it is found in a few multicellular animals and quite a number of the highest plants. Thus a strawberry plant sends out "runners," and from the tips of these new strawberry plants grow. The runners then decay, leaving several plants which have arisen from one. Reproduction by cuttings is akin to this. Amongst animals the members of the group to which hydra, the jelly-fishes, and corals belong reproduce commonly by dividing. The same thing is normally true of many worms (and we can make it accidentally true in the common earthworm by cutting the animal in two); each half may then regenerate the lost part. Obviously this method of reproduction must be very limited in the higher animals, for one cannot conceive of a highly complex animal dividing into two parts.

Instead of this, the multicellular animals produce certain special cells, the germ cells. These are set free and from them, by repeated division, growth, and differentiation, new individuals are produced. The parent animal eventually dies. The separation of certain cells from the body and their eventual growth into new individuals is not *in itself* very different from the separation of more complex parts, as when a worm divides into two or a rose-bush has a cutting removed from it. What *does* make it different is another phenomenon which is usually closely tied up with it—namely, sex. So much is this the case that we speak of all forms of simple fission, reproduction by cuttings, etc., as *Asexual Reproduction,* as contrasted with *Sexual Reproduction,* in which plants and animals produce special reproductive cells. Asexual reproduction only concerns one individual, and it does not matter whether it be male or female, or whether there be any distinction in sex in the animals or plants concerned, while almost always in sexual reproduction specialised parts of *two* individuals are involved. If we examine any species of frog by dissection, we shall find that there are individuals of two kinds (females and males), one of which possesses ovaries, which produce " eggs," whilst the other has comparable organs, the testes, which produce germ cells called spermatozoa. Had both types of germ cell been alike in structure, there would possibly have never been any distinction between the animals bearing them, and consequently no sexual differences. On the other hand, it is equally possible that without the existence of some sort of difference between the protoplasm of individual organisms (whether multicellular or single-celled) there would never have been what we call sexual reproduction.

Everyone has seen some sort of egg. Extremely few people have seen individual spermatozoa (although it is very easy to do so). The reason is that most eggs are big enough to be visible with the unaided eye. Spermatozoa are so small that they need a microscope to make them visible. They were seen in 1677, but it was not until 1824 that it was definitely realised they were alone responsible for fertilisation; previously the fluid containing them had been accepted as a "fertiliser." Some animals produce both kinds of germ cells; they are called *Hermaphrodites* (the earthworm is one, the common garden snail is another). Under no conditions can a spermatozoon be made to grow up into a new individual, nor will the egg do so either unless certain conditions are fulfilled. Normally it is necessary that one egg and one spermatozoon should meet and fuse together. The product of their union is known as a fertilised egg and, given the right environment, it very soon commences that remarkable growth which leads to the production of the adult. The astonishing thing is that this sexual reproduction is well-nigh universal, and amongst plants as well as animals. There must be something very important in this curious complication of reproduction, for very little observation shows that it is a serious complication, and one that is not to be taken too much for granted. Why should there be *two* kinds of germ cells? Why should there be sex? Why should *two* germ cells have to make a complete union in order that a new individual should arise? These are the fundamental points in the puzzle of sex.

The case rests as follows. Reproduction is a universal feature of living organisms; without it life would come to an end. There are various types of successful asexual reproduction, but the sexual method is almost always present in addition. Yet compared with asexual reproduction it is not economical. One has only to glance at the animal world to see this, for sexual reproduction practically always means two parents. A male and a female plaice or herring must be in proximity to each other at the breeding season. Each sheds its germ cells into the sea. Millions of spermatozoa must be produced to provide any certainty of the eggs being fertilised. Indeed, all the romance of sex amongst plants and animals, and it is a romance, is interwoven in Nature's efforts to bring about the union of these germ cells. Why such wasteful methods when asexual reproduction can be successful?

When a sperm cell meets an egg and fuses with it, the nucleus of the sperm cell passes right inside the egg and still moves on until it meets the nucleus of the egg. The two then fuse and make one. Shortly afterwards the fertilised egg begins its development. Experiments have shown that we can distinguish two quite separate actions in this fertilisation union. All the world was startled when, in 1906, Loeb, an American scientist, showed that it was possible to make eggs develop without the presence of sperm cells at all. The stimulus which replaced that of the sperm cell was chemical. Starfish eggs can be made to develop by placing them for a short time in sea water which is a little more concentrated than normal, or has various other elements added to it.

Other stimuli have been discovered which may set an unfertilised egg developing; frogs' eggs, for example, can be made to do so by pricking them with a fine needle in the presence of a little blood. Here, then, is our first clue. Since the stimulus to development need not necessarily be fusion with another cell, we may deduce that the egg cell contains within itself the complete mechanism for the formation of a new creature. Other experiments have shown that as a result of normal fertilisation the sperm cell and the egg can, notwithstanding their different sizes, contribute equal shares in the characteristics of the offspring. Children may inherit as much from the father as from the mother. These observations provide our second clue, and, putting the facts together, it is legitimate to conclude that in fertilisation the sperm cell provides (1) the stimulus to further development, and (2) hands over in its nucleus a material bequest of hereditary characters. Now, since we can easily replace the stimulus to development artificially, and since in Nature there are many cases where eggs do develop without fertilisation (certain eggs of the honey bee, the green aphids, etc.), we may go a step further and say that it is the second result of egg and sperm union that is really important—*i.e.*, the mixing of living substance from two different organisms, the mixing of two sets of hereditary characters. It is difficult to see how this could be achieved in either plants or animals, except at the comparatively simple stage when they are represented by the germ cells. Sexual reproduction provides, therefore, the mechanism for a mixing of living substance of at least two different cells, generally from two different individuals.

(It is unfortunate that the term "fertilising" is used so often in everyday life for the application of chemicals to vegetable growth to stimulate it and provide food. It tends to exaggerate the importance of the egg cell in animal reproduction, and to stress the action of the male cell as that of a stimulant to further development. It must be kept in mind that this stimulating action is secondary to that of the mingling of two sets of characters.)

Why should sexual reproduction have brought with it males and females, which are often very different in appearance? It is not difficult to suggest an explanation. The germ cells are very frequently shed and left to develop further. Some material for the construction of the new individual must be supplied until it is capable of absorbing food itself. At the same time it is essential that the germ cells should have some power of movement, even if slight, to facilitate their union. Nature has again specialised; the cell which we call the egg stores the food material and has no power of movement; the spermatozoon lacks all food store, and is very small, but it is active. This difference in the germ cells is obviously going to be reflected at least in the internal structure of the animals producing them.

If that were all, the only difference between males and females might be internal. Such is actually the case in many animals, especially those which are aquatic and shed their germ cells into the sea, where their union is somewhat a matter of chance. But it is no use shedding delicate germ cells on land, and sperm cells are, of course, adapted for motion in a fluid medium. Thus, with the advent of life on land and in the air, other mechanisms had to come into existence for bringing sperm cells into the immediate neighbourhood of egg cells. This not only led to big differences in structure between males and females, but to differences in habits, and to a vast diversity of devices for making reproduction more certain and less wasteful. Even amongst aquatic animals we meet the same thing. Finally, we find arrangements for the protection of the eggs *after* fertilisation and whilst undergoing their early development. To this end they may either be nursed and guarded by the parents or kept within the body. The culmination of the process is seen in the highest animals, the mammals, where the eggs are not only fertilised within the body of the mother, but kept there until a very high state of development is reached, when birth takes place. In brief, sperm cells are practically always passed out of the animal producing them; eggs may be shed or may be retained for a shorter or longer period during development.

It is interesting to see how certainty of fertilisation and safety during development is reflected in the number of germ cells produced. Aquatic animals, which simply shed their eggs and sperm cells into the water, produce incredible numbers—a female turbot, 9,000,000 eggs per annum; the codfish, 6,000,000 eggs. Heaven only knows what the number of the spermatozoa must be in these cases. (It has been calculated that in man there are approximately 850,000,000 for each egg produced in the life of the female!) The eggs of the dogfish are fertilised within the body of the female, and are laid enclosed in a protective shell; the female dogfish only produces a few eggs in a year.

The female housefly lays its eggs on refuse in batches of a hundred or more at a time, and five such batches in its summer life. On the other hand, the African tsetse fly, notorious for its transmission of the parasites causing sleeping sickness, retains its fertilised eggs within its body until they have developed beyond the early stages; it produces only one young at a time. Certainty of fertilisation (usually only ensured by the male inserting the sperm cells directly into the female) and parental care of the young save the enormous wastage which otherwise occurs.

It is not remarkable that the conger eel and probably a high percentage of salmon never survive their single breeding period; the marvel is that so many animals do survive. No one who studies reproduction can fail to see the heavy price paid for the continuance of the species. Nor can one miss the driving force in the instincts behind it. All the romance and all the tragedies of human history whose causes lay in the loves of man and woman are reflections of that urge to safeguard the race which is traceable from the simplest creatures upwards.

In some animals periods of asexual reproduction alternate with sexual reproduction. For example, the common freshwater hydra, during the summer, throws out small "buds" on its sides, and these become detached as independent individuals; it is a form of simple fission. In autumn, eggs and sperm cells are produced, and the eggs, after fertilisation and a brief period of development, rest as a resistant stage through the winter until a more favourable season returns. Numerous cases may be found where, during seasons when food is plentiful and all the conditions are favourable, reproduction takes place asexually (and hence without the waste and delays which seem so often associated with the sexual method). The green fly, that wretched plant pest which torments lovers of rose-gardens, provides another example of this; but it is not quite correct to call it alternation of asexual and sexual reproduction. With warm air and favourable conditions successive generations of females are found. Each insect lays eggs *which develop without fertilisation,* and all turn into females. Males are dispensed with. It is easy to see how enormous numbers appear in a short time. But after a comparatively long period arrangements are made for the intermingling of protoplasms, and before winter comes males as well as females are produced. The females of this generation lay eggs which *do* require fertilisation.

The phenomenon of the development of eggs without fertilisation at all is called *Parthenogenesis.* In one or two cases in the animal world it has reached such a point that males have become non-existent. Fertilisation is unknown; all the individuals are females.

The honey bee presents us with parthenogenesis under another aspect. The queen bee—*i.e.*, the fertile female, is impregnated with spermatozoa by a Drone (a male). After this she can go on laying eggs for a year or two, and can control their fertilisation. If an egg is fertilised before it is laid, it becomes a female; if it is not fertilised, it develops all the same (parthenogenetically), but becomes a male.

Parthenogenesis reminds us again of the discovery that some eggs can be made to develop by artificial means. It is further confirmation of the idea that the fertilisiation union of germ cells is primarily something other than reproduction, although the two things have become associated so very, very closely.

In seaweeds, mosses, and ferns sexual reproduction is very like that seen amongst animals. In fact, the easiest way to demonstrate to students the fertilisation of an egg cell by sperm cells is to experiment with the common, brown seaweed of our coasts. Amongst plants, however, one frequently meets with what is called *Alternation of Generations.* The common bracken fern produces tiny bodies, the spores, on the underside of its fronds. These fall on the damp soil and develop into little green plants called prothalli, about a quarter square inch in area, and quite unlike fern plants. This is asexual reproduction. It is on these prothalli that the organs containing germ cells analogous to eggs and sperm cells are produced, and then fertilisation leads once again to the bracken fern stage.

This alternation of asexual and sexual reproduction is found right up to the so familiar flowering plants, but, unfortunately, it is not so easily demonstrated. The fern prothallus is very small indeed when compared with the bracken fern stage. In the higher plants this sexual stage becomes smaller and smaller until finally it ceases altogether to have an independent existence, and one must look for it on the asexual plant. The pollen grains (so often wrongly compared to animal spermatozoa) are, in reality, the spores from which develop the most minute male sexual stages; the ovules (often compared with animal eggs) are really sporangia. Pollination of flowers—*i.e.*, the carriage of pollen from one flower to the central part, the stigma, of another, is consequently not at all comparable with a sperm cell being brought into contact with an egg.

Growth is so characteristic of all living things that it is often taken very much for granted. It is not mere increase in size, although that would in itself be interesting, for it implies the conversion of non-living substance into protoplasm. The term as used in biology covers some extraordinary phenomena, including processes which have been utilised more than once in the conflict between the mechanists and vitalists. An amœba may grow by a simple increase in size; a multicellular animal developing from an egg increases in size, but at the same time it becomes different in shape and appearance, and its parts gradually become materially different in constitution. Let us commence with the fertilised egg of a frog. It initiates its development by dividing, and, divisions continuing, a large number of smaller cells result. Then the cells (all of which are simple and undifferentiated, like the egg cell which gave rise to them) begin to arrange themselves in this way and that way. Cell division continues, here faster, there slower, until by division, by folding, by rapid growth here and slow growth there, a definite form is gradually moulded and the foundations of different organs are laid down. But what are the forces which control this moulding, and where are they situated? At first one was tempted to suppose that the fertilised egg contained factors for the growth of the complete organism, and that at each division these factors were shared out. The case turns out to be different. Experiment shows that normally the first division of the frog's egg gives two cells, each of which will be the progenitor of all the cells of one half of the body. If, however, these two first cells are carefully separated (without injuring them), each goes on dividing, and two complete individuals result. Clearly there has been no sharing out of factors. All the evidence tends to show that the moulding of the developing embryo is, in some way, dependent upon the proximity and interaction of the cells of which it consists, but a controlling mechanism at this stage is hidden.

As events proceed further a little more information can be gained. For example, at one period an outgrowth of cells from what is clearly the fundament of part of the brain appears exactly opposite an ingrowth of cells from the outer surface of the embryo. Events show that these two growths will combine to form an eye, one becoming the lens, the other the retina. By extremely delicate manipulation it has been possible to remove one or other of these growths, and as a result it has been demonstrated that the ingrowth of the outer layer to form a lens is a response to the presence of the retinal outgrowth of the inner layer. Indeed, it is possible to make an altogether different region of the outer layer of embryo grow inwards to form a lens by transplanting the retinal outgrowth underneath it. This is the kind of experiment which is being made to find out why a tiny "blackberry-like" mass of cells should divide and redivide, with a spontaneous marshalling of the resultant cells hither and thither into layers and folds and tubes, until out of it all a tiny embryo results.

Let us assume that the organs of the adult have now been mapped out; their cells are still embryonic and undifferentiated. From this point growth includes increase in size, multiplication of cells, and *Differentiation,* which means that the cells become specialised and unlike in form and structure. Regulation is continuously manifested, and each part (if conditions are normal), just balances its neighbouring parts. Eventually, after some vicissitudes, the adult stage is reached, and growth phenomena slow down or come to a standstill altogether. Finally, even cell life appears subjected to some "braking" process; a condition of senescence replaces that of activity, and ultimately death occurs. It is only natural, especially after a study of the "immortal" protozoa, to ask why growth ceased, and what prevented the continued existence of the animal.

The power of growth, as expressed by cell division, seems to disappear as cells become differentiated or specialised in structure and function. But the power of growth is not always lost when an animal is grown up and its tissues differentiated. Hair on a mammal continues to grow even in old age; cuts in the skin heal up. A lizard has often escaped me in the Australian Bush, because in an excited chase I have gone eagerly after what turned out to be its thrown-off tail. A new tail with muscles and other tissues is grown by the animal. On the whole, however, tissues do not grow after they have differentiated. This is quite in accordance with the lizard's tail example, because if examination be made of the growing stump it will be found that the tissues of the new tail are not growing direct from tissues of the stump, but from a mass of undifferentiated cells which have appeared from somewhere. Possibly a few cells, retaining their embryonic non-specificity, were lurking amidst the tissues at the base of the tail before it was broken. It is not impossible, however, that some differentiated cells " went back on their tracks," so to speak, and dedifferentiated. This rather startling conversion can actually be produced: it is also found in malignant tumours. With dedifferentiation the power of growth and cell division returns, and unfortunately, in the case of malignant tumours, the uncontrolled growth continues. There seems no limit to the life of such cells, and a tumour can be transplanted through generations of mice without coming to an end.

Much light has been thrown on the subject recently by experiments in the culture (in little glass dishes) of tissues taken from living organisms. Arising out of the successful culture in nutrient media of all sorts of bacteria (a commonplace to-day of bacteriological laboratories) the culture of animal tissues has turned out to be far more interesting than was anticipated. Cells which have ceased to grow in the animal from which they have been taken, may start afresh when isolated in the culture media. Specialised tissue may be seen to dedifferentiate into non-specialised—*i.e.*, embryonic, cells again and the power of growth is regained. After generations and generations of such embryonic cells the introduction of a piece of normal tissue into the culture may cause differentiation once more.

Everything indicates that growth is characteristic of living protoplasm, and that where this is not taking place some repressing factor is present. Such repressing factors come into play as any animal's body is normally developed. On the other side, certain substances appear necessary in order that growth may take place, and there are other substances which appear to "speed up" growth and protoplasmic activity in general. Vitamin D has already been referred to in this respect, and mention has been made of the secretions of the ductless glands in the bodies of vertebrates. Cretins are the result of deficient development of the thyroid gland, and in many cases a dwarfed, ugly, imbecile, cretinous child has been changed into a normal creature by feeding with thyroid gland taken from other animals.

The well-known galls and other abnormal outgrowths on plants are due to a growth stimulus exercised by substances injected by insects, or by substances given off by insect parasites. In the case of malignant growths it is not necessary for the initiating stimulus to be continued; active cell growth once re-established seems to go on automatically.

No one has yet satisfactorily explained senescence in the multicellular animal, except in so far as specialisation and differentiation mean loss of growth power. Since protoplasmic life implies wear and tear and replacement, any difficulty in performing the latter is bound to result in death sooner or later. Probably no human beings have ever died as the result of uniform and natural senescence of the tissues of the body. Something happens to one or other organ before such a condition is reached. Accidents happen, bad environments and bad habits all conspire to upset the equilibrium of the organs in our big but restricted cell community, and when natural senescence is only just beginning, temporary low conditions may enable disease germs to find a lodgment where once the body might successfully have dealt with the invaders.

Whether natural senescence can be postponed is another question for the future. Remarkable results have recently been claimed for rejuvenation, following the transplantation into man of the testicular glands of other animals. The future will show whether this is merely a reawakening of sexual instinct or a true rejuvenescence.

CHAPTER VII

ORGANIC EVOLUTION, HEREDITY, AND SEX

One can safely assert that no theory in science has been the source of more public discussion than that of *Organic Evolution*. No doubt this is due to the fact that the theories of astronomers, geologists, and other scientific workers have never touched popular religious beliefs so closely. The result might well be expected—no theory in science has been so mutilated and so misconceived as that of organic evolution. Even to-day popular writers frequently assume that the theory of evolution is the same thing as Darwin's theory of Natural Selection, and thus when they hear that Darwin's theory is the subject of discussion and criticism by scientists they jump to the erroneous conclusion that the great concept of evolution is the subject of the attack.

The idea of organic evolution is no novelty of the past century. From the time of the great Greek civilisation the idea has slowly gained ground that animal and plant life has gradually unfolded itself, branching out into all the varied forms existing to-day (and including all those which have become extinct in past ages). With the ever increasing mass of anatomical knowledge, it began to assume much more definite form in the period (1700-1800) before Charles Darwin's birth, until ultimately a very definite theory of evolution was propounded by Lamarck in 1809, the same year that Charles Darwin was born.

The way had not been paved for the acceptance of such a theory, and certainly before Lamarck's time most theories had been exceedingly speculative. During the short period between Lamarck and Darwin the "atmosphere" changed somewhat, and the publication of Lyell's principles of geology in 1832 created an altogether new situation.

Charles Darwin, after having spent twenty-two years in accumulating and setting out his facts, produced an overwhelming volume of evidence for evolution, and, in addition, furnished an ingenious theory for the *modus operandi* of the evolutionary process. His theory was first published in book form in that classic, *The Origin of Species,* in 1859. The first public exposition was in the previous year at a meeting of the Linnean Society in London, and at the same meeting a paper was read by Alfred Russell Wallace who, by one of those extraordinary coincidences, had come to practically the same conclusions as Darwin in regard to evolution by Natural Selection.

Since Darwin's time all thinking people have come to accept evolution as the only logical way in which the living world can be interpreted and understood. One might affirm that the concept of evolution made biology a science. Apart, however, from the importance of evolution on the theoretical side, there is a practical issue. The study of evolution is linked with the study of heredity, and both enter into modern investigations in medicine and in animal and plant breeding.

Many discoveries of science are accepted with keenness by the everyday world when they become of commercial value; others just as remarkable are ignored because they have not yet any "cash value." The evolutionary theory occupies a different place; it attracted popular attention because it conflicted with a belief in "Special Creation." But one might point out that Special Creation is *only one way* of interpreting the first chapter of Genesis, and that one the least thoughtful and least inspiring. It is just as well to regard the description in Genesis as "a simple story beautifully told, derived from Hebrew tradition and well suited to the state of knowledge of the times and of the people for whom it was written" (Lull).

If the concept of evolution stands firm to-day, it is quite a different matter in regard to the explanatory theories. Obviously there could be no evolution if there had been absolute identity between parents and offspring. Now it is well known that differences (large and small) between parents and offspring, brothers and sisters, exist everywhere in the animal and plant worlds. These differences (or more accurately, perhaps, the degrees of difference) are known as *Variations*. They are the material basis of evolution, and if we had a complete understanding of the forces which controlled them, we should probably have a complete explanation of the evolutionary process.

The subject is now so vast that we cannot attempt to say more here, and in any case it would be needless duplication, for books on Evolution and Heredity are appearing in the present series. We shall have served our purpose if we indicate that the study of the *modus operandi* of Evolution is still in the foreground of biological research, and that whilst Darwin's theory of Natural Selection is very strongly held to-day, there are many biologists who will only accept it as one of the ways in which evolution may have progressed.

The study of *Heredity,* which is so closely intertwined with evolution, has brought to light such remarkable discoveries that once again we have to refer the reader to another treatise for detailed information. Originally, research in heredity was entirely a matter of observing the results of breeding. A new aspect was introduced when Mendel's discoveries of certain laws were made known in 1900. It is now actually possible to prophesy fairly exactly what will happen when certain animals or plants are crossed.

Modern investigators have carried the matter much further than this, and it has been possible to show (by means of the microscope and with the aid of elaborate staining technique) an actual structural mechanism in the cell nucleus which is concerned in heredity. The microscopic study of the germ cells now goes hand in hand with breeding experiments, the results of the former explaining those of the latter. Out of the vast assemblage of results, one picked at random will serve to illustrate the type of some modern work.

The human disease hæmophilia is marked by an inability of the blood to clot when a bloodvessel is cut and the blood escapes (obviously a dangerous character, for clotting is a natural way of preventing loss of blood). It only occurs as an inherited character and *is only present in males,* although evidence shows that it is inherited from the mother who herself shows no signs of hæmophilia.

Exactly the same type of inheritance is found in a small fruit fly, where white-eyed flies appear in the progeny of certain crosses between red-eyed flies, and all these white-eyed flies are males. We can perform all sorts of breeding experiments with these flies, and we can with little difficulty bring to light the microscopic structure of their germ cells. Such research shows that a factor for white-eye colour has been carried in the nuclei of the cells of the red-eyed mother and is present in all her eggs. What happens in the succeeding generation depends upon the nuclear constitution of the sperm cells which fertilise these eggs. There can be no reasonable doubt (from the results of other investigations) that exactly the same type of mechanism explains hæmophilia in man, which is inherited in a similar manner.

This example leads naturally to another question of paramount interest in biology at present, the phenomenon of *Sex*. What determines whether a fertilised egg will grow into a male or a female? The investigation of this problem is receiving great attention, not only because the problem in itself is interesting, nor because knowledge of the factors might enable us to control sex, but because events are indicating that this line of investigation will provide another method for elucidating the mechanism of heredity and possibly some of the deeper phenomena of life itself. At present we know that in the majority of cases sex is determined (fixed) at and by the union of egg and sperm cell when the former is fertilised. Apparently both the egg and sperm carry factors for sex just as they carry factors for other characters which are inherited. But the matter is not quite so simple as this, because many examples are known where the sex of an individual has changed during its life. (Poultry farmers are now quite familiar with hens which, owing to ovarian disease, take on the plumage and even other sex characters of the cock.)

From such examples we might conclude that probably all fertilised eggs possess factors for the inheritance of all the characters possessed by either sex, and that which set actually develops is a matter of the interaction of certain other factors brought together at fertilisation, an interaction which, quite conceivably, might be influenced later by the environment (using the term in the widest sense).

CONCLUSION

THE MODERN TREND OF BIOLOGY

WE have endeavoured in the preceding pages to indicate the kind of problems which the biologist is facing to-day and some of the fundamentals upon which these problems rest. There are many branches of biology and all serious workers are specialists. It is not difficult, however, to distinguish one particular " surge " in which discoveries in every line of research play a part. It is the effort to explain life itself. The living cell is to the biologist what the molecule has been to the chemist. Can the living cell be completely explained by physico-chemical theories of the same order as those which have led to so much progress in the past?

There have been many battles between so-called mechanists and vitalists; and the vitalists and neo-vitalists, with mysterious vital forces, an *élan vital* (Bergson) or an *entelechy* (Driesch), do not seem to have emerged very happily from their conflicts. The mechanists, on the other hand, are perhaps unduly confident, although one must admit the wonderful results of the application of mechanistic principles. To-day, however, there is a changed atmosphere in science, and when a professor of mathematics can write: " Time, space, matter, material, ether, electricity, mechanism, organism, configuration, structure, pattern, function, all require reinterpretation. What is the sense of talking about a mechanical explanation when you do not know what you mean by mechanics?" it would appear that biologists, too, may have to look towards a new philosophy.

Meanwhile, the discoveries in heredity have reached a stage of great practical importance, with an ever increasing possibility of human application. Laws will probably have to be modified, and much social change may result. Our increased knowledge of the factors which are necessary for life (including the recent developments in regard to vitamins, ductless glands, tissue culture, sunlight, etc.) are being crystallised into a great effort for the prevention of human disease. We are only beginning now to apply a little of the knowledge already gained. The entomologist is pushing home his attack against insect pests, the fisheries expert is watchful of the productivity of the seas, the application of botanical investigation is a necessity in successful agriculture. No animal or plant is or can be excluded from investigation, and one never knows where or when an observation will be made which will open up a new avenue of inquiry.

> " A hair perhaps divides the False and True;
> Yes; and a single Alif were the clue—
> Could you but find it—to the Treasure-house,
> And peradventure to The Master too."
>
> *Omar Khayyám.*

One scarcely dare prophesy the possible results. The past fifty years have seen amazing changes consequent on the discoveries of chemistry and physics and our resultant control of machines. Biology will work far greater changes than these, as its discoveries bring the possibility of controlling the living organism. One can only hope that man himself will advance, and be better fitted ethically to take command of the powers now granted him.

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AN INTRODUCTION TO ZOOLOGY

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AN INTRODUCTION TO ZOOLOGY

CHAPTER I

INTRODUCTION

ZOOLOGY is the science of animals. Dealing as it does with the scientific study of animal life from the lowest microscopic creature up to man, it is of enormous scope and cannot be mastered by any one mind or summarized between the boards of any one book. But its very extent and the vast variety of its data make it peculiarly necessary, in the case of Zoology, to commence its study with a general introduction which, to the student, will provide a framework, any part of which can be filled in in detail later, and to the ordinary citizen will provide an outline sketch of what is meant by Zoology. And it may be mentioned that there are at the present time signs of a growing appreciation of the need of every citizen of a civilized community having clear in his mind some of the basic zoological principles upon which the success of communal life rests.

The study of any particular animal falls naturally into two main branches: (1) Anatomy, which deals with its appearance, form, structure; and (2) Physiology, which deals with living activities, the functions of the body and its parts. Each of these two main departments of zoological science, while based upon observations of single individual animals, stretches out into regions which involve a broader outlook. Thus, anatomy leads to Comparative Anatomy, involving the comparison of different individuals and different kinds of individuals with one another; to Embryology, which concerns itself with the development of the individual from the egg to the adult; to Systematic Zoology or Taxonomy, which deals with the classification of animals according to their resemblances and differences; to Zoogeography, which deals with the geographical distribution of the various kinds of animal, and to Evolutionary or Historical Zoology, which concerns itself with the past history of the animal kingdom.

So also with Physiology, which spreads out from the intensive study of a single type of animal into Comparative Physiology, and finally into the functional relations of living animals to their environment. This latter corresponds to the wôrk of the field naturalist, and is only gradually, under the title Ecology or Ethology advancing towards the position of being a precise and properly ordered science.

The two main departments of zoological science have, owing more particularly to the differences in training and technique demanded of their votaries in order to attain success as investigators, tended to become separated in watertight compartments; but it is to-day becoming more and more clearly recognized that this separation, if absolute, involves the danger not merely of sterility as regards general ideas, but even of liability to serious error.

The zoologist should then, when investigating structure, always keep before him the fact that the creature he is studying was once alive, and that its parts had to carry out efficiently their living functions, while similarly the student of function should throughout think of the living functions in terms of the organs by which they have to be carried out.

The retention of breadth of vision is, in fact, one of the chief desiderata to-day for those entering on the study of Zoology. Like other subjects, Zoology has suffered greatly from the mere accumulation of detail. To those commencing the subject the temptation is great to set about adding a few more details, and, once embarked on the path of indiscriminate detail collecting, the temptation persists to continue on this soothing but deadening occupation regardless of the fact that the mere accumulation of details tends to hide away the general principles which make a science alive and to scare away the most promising recruits, whose ambition is not merely fact collecting, but the puzzling out of Nature's great philosophy of which facts are merely the symbols.

CHAPTER II

A SIMPLE TYPE OF ANIMAL—"AMŒBA PROTEUS"

THE most satisfactory way to commence the study of zoology is to study intensively some type of animal which combines extreme simplicity of structure and function with being amenable to the methods of observation at our disposal. Such a creature is *Amœba proteus,* which may be found creeping about on the muddy bottom of freshwater pools, where the water is rich in oxygen and other conditions favourable. Just visible to the naked eye as a tiny white speck, the Amœba has to be examined with the microscope in order to make out its main features. It is then seen to consist of a little blob of living substance or protoplasm—what Huxley called the physical basis of life from the fact that life has never been observed apart from this protoplasm. What gives protoplasm its transcendently interesting attribute—that it *lives*—is quite unknown. Science has not the slightest inkling of what it is, and there is little encouragement to think that it will ever be otherwise when we reflect that the intellectual operations of man's brain through which we would tackle the problem are themselves activities of this same living substance. A corpse is a poor thing in comparison with a living body, but it is at least possible to subject it to the operations of chemistry, and when this is done with the dead remains of protoplasm it is found that these dead remains consist of proteins—compounds of carbon, oxygen, hydrogen, nitrogen, and sulphur, united into huge molecules, the size of which makes them behave as colloids, but the atomic architecture of which is not yet certainly determined.

The blob of protoplasm constituting the living amœba is seen under the microscope to be differentiated to a certain extent. The greater part of it, known as the endoplasm, is a liquid carrying in suspension innumerable minute granules, giving it a characteristic grey or almost white appearance when observed by reflected light. These minute granules differ in composition: some are minute droplets of water; others droplets of fat; others tiny crystals of waste materials, such as calcium phosphate. The body of the amœba is bounded by a surface layer of ectoplasm—a layer of protoplasm differing from the endoplasm by its glassy, transparent appearance; it is without the granules so conspicuous in the endoplasm. Finally, lying in the endoplasm is a comparatively large nucleus, a thick circular disc which, as will be seen later, is of great physiological importance. The analysis of dead nuclei shows them to be characterized by the richness of their proteins in the element phosphorus, while staining the amœba nucleus with certain dyes shows it to consist of two different types of substance—the main nuclear substance or chromatin forming little blobs close to the surface and characterized by its taking on the stain particularly deeply, and the other, achromatin, which remains comparatively pale.

Such are features that can be made out in the dead amœba; but if the specimen is alive and active many more details can be observed which go to constitute the physiology of the creature. First of all, its method of movement—so characteristic that when observed elsewhere in the animal kingdom it is referred to as amœboid movement. In this type of movement the surface of the body is slowly pushed out into blunt, finger-like projections called pseudopodia, the liquid endoplasm streaming out into each pseudopodium as it is protruded. The pseudopodia may have the appearance of being pushed out indiscriminately in any direction. At any one moment some are being pushed out while others are being withdrawn.. Normally, however, continued observation shows that pseudopodium-protrusion is somewhat more active in one direction, for the amœba gradually changes its position, becoming slowly transported in a particular direction—at a rate of, it may be, as much as 3 mm. an hour.

This amœboid movement, as well as being the most conspicuous of the amœba's living activities, is also the simplest of them all. It should be emphasized at once that we do not yet have any clear understanding of the vital processes which find their expression in amœboid movement. We may speak of the protrusion of a pseudopodium as being due to the slackening of surface tension over one part of the surface which "gives" and is pushed out by internal pressure, but we cannot go much farther; we do not know for certain to what extent changes of the colloid protoplasm between the gel and sol condition are involved and what are the living processes which bring about any such changes.

Until we have a clear comprehension in terms of physics and chemistry of this very simplest phenomenon of living substance it would appear to be not merely vain, but ridiculous, to erect, as is sometimes done, an edifice of speculation as to what is the nature of life itself, based upon observations of physiological operations, of far greater obscurity and probably of far greater complexity, in animals higher in the scale.

When amœbæ are observed in company with numerous smaller creatures, they may often be observed to feed. The protoplasm of the amœba wells up round the body of a food organism between it and a solid surface, such as that of the glass cover-slip through which it is being observed. The deeply embayed food organism becomes completely enclosed along with a little water by the protoplasm of the amœba flowing completely over it. The food organism is thus enclosed in a food vacuole. If an actively moving creature, it may be seen for a time dashing wildly against the walls of its prison, but its movements gradually slacken and stop, and death takes place apparently through some poison secreted by the amœba's protoplasm into the food vacuole. Chemical tests show that the fluid in the vacuole has become acid in reaction, so we may conclude that the poison which has killed the food organism is an *acid* secretion. After the death of the food organism, but not until then, the process of digestion begins. If the food organism happens to be green its colour is seen to darken and later to change to a brownish colour. Its outline becomes gradually blurred, and its substance disintegrates. It is undergoing digestion by the activity of one or more of these mysterious factors known as enzymes or ferments, which have the power of inducing or accelerating chemical change of a specific kind in substances with which they are in contact.

An interesting detail to note is that during digestion the fluid in the food vacuole loses its acid character and becomes alkaline. In this respect the digestive ferments of amœba resemble the tryptic ferments of higher animals, which also act in an alkaline medium.

The end result of the digestive process is that the dead protoplasm of the food organism is broken down into simpler chemical substances, which can be assimilated by the living protoplasm of the amœba. From what can be observed in amœba, we learn a fundamental principle applicable to animals in general—namely, that living protoplasm is never able simply to appropriate and add to itself other living protoplasm, but that, on the contrary, food protoplasm must be firstly killed and secondly digested before it can be assimilated. Until protoplasm is dead it is, in fact, entirely immune from the disintegrating effect of digestive ferments: thus the living wall of the food vacuole is quite unaffected by the digestive ferments in its cavity.

After the completion of the digestive process and the absorption of the products of digestion by the living wall of the food vacuole, all that remains in the latter is the scanty indigestible débris of the food organism. This "fæcal" material is got rid of by the food vacuole approaching the surface of the amœba and bursting to the exterior as soon as it touches the surface film.

A conspicuous feature in the living amœba is the contractile vacuole—a spherical vacuole filled with watery fluid. This may be as large as the nucleus, but its most arresting feature is not its size, but its behaviour; for it suddenly vanishes, and presently there appears in its place a very small droplet of fluid, which gradually increases in size until it reaches the full size, when again it vanishes as before. A clue to the instantaneous vanishing of the contractile vacuole is obtained by observing a living amœba in water thick with particles of Indian ink, for each time the vacuole disappears these are seen to be pushed back by clear fluid extruded by the contractile vacuole. The latter is, in fact, a pump which is continuously passing out water to the exterior, the water being replaced by what is brought in with the food, and imbibed by the general surface of the body. The cycle of the contractile vacuole commonly occupies from five to eight minutes. Its activity ensures that the living protoplasm is constantly being flushed by fresh water, which serves a twofold purpose: (1) Respiratory or breathing, in that supplies of oxygen are brought in dissolved in the water, while carbon dioxide is got rid of; and (2) excretory, in that the poisonous waste products are washed out and excreted to the exterior.

It will already have been gathered that the amœba grows, for it assimilates the products of digestion, and thus adds to the amount of its living substance. But it will also be understood that such growth cannot go on indefinitely. On the one hand, the amœba, being a blob of fluid protoplasm, would lose its cohesion and simply flow out into a thin layer if its protoplasm were to increase beyond a certain amount. On the other hand, were it possible for the amœba to retain its cohesion and typical form, continued growth would make the area of its surface, upon which it depends for the absorption of water with its contained oxygen, less and less sufficient, seeing that an increase in the amount of protoplasm represented by the cube of a particular number would mean an increase in the area of the surface, corresponding roughly to the square of the same number.

The corrective by which Nature guards against this danger is the process termed fission, in which the amœba divides into two daughter amœbæ of equal size, each containing a nucleus—the original nucleus having divided into two before the main mass of protoplasm. In this way the adequate proportion of surface to bulk is restored, and the two young amœbæ proceed with feeding and growing until the size limit is again reached and the process of fission repeated.

The fission of the amœba is of interest not merely as a corrective to the increase in size; it is also of interest as a form of reproductive process—the simplest of all forms of reproduction, in which the parent simply becomes resolved into the two offspring. So far as is known, this type of reproduction may go on indefinitely so long as conditions are favourable to the life and health of the amœba. An important point to notice is that the succession of generations produced in this way does not involve death. It would appear, in fact, that in such lowly unicellular creatures death is not an essential sequel to life as it is in the more complex animals.

If, however, conditions become unfavourable, a different type of reproductive process makes its appearance. The nucleus becomes resolved into numerous small nuclei, which become scattered through the body of the amœba. Round each there concentrates a little spherical mass of protoplasm which becomes enclosed in a protective cyst or shell. The numerous cysts are for a time enclosed in the moribund and dead superficial layer of the parent's body, but eventually this disintegrates and the cysts are set free. They lie about at the bottom of the water until the conditions again become favourable, and then the little mass of protoplasm in each emerges from the cyst as a tiny amœba, with rather pointed pseudopodia, which, if food and other conditions remain favourable, has, at the end of about six months, grown up into an amœba like its parent.

Such are the more important points that have been made out by merely observing amœba under natural conditions, but, just as with the physiology of the higher animals, many additional and important facts have been made out by the use of the experimental method. It is, for example, possible to divide a living amœba into two halves with a fine cutting instrument.

When this is done the smooth, dense nucleus, if touched by the instrument, commonly slips to one side, so that the result of the operation is a couple of blobs of amœbic protoplasm, one of which contains the nucleus, while the other is without a nucleus. Important differences soon become apparent between the two. The nucleated portion behaves in every way like a normal amœba, creeping about, ingesting and digesting food, growing, and eventually undergoing fission. There is, however, one important detail to notice—namely, that there takes place a gradual shrinkage of the nucleus until it comes to bear about the same proportion to the whole protoplasm as was the case in the original amœba. Here we have the expression of an important general principle, that there is a definite normal proportion between the size of the nucleus and that of the mass of protoplasm surrounding it.

The non-nucleated bit of the amœba, on the other hand, shows conspicuous abnormalities correlated with its being without a nucleus: (1) It dies after a few days, being incapable of continued life; and (2) while it may take in a food particle into a food vacuole it is unable to carry out its digestion; the absence of a nucleus precludes the process of secretion.

Taking the whole study of the amœba, we learn from it many of the most important basic principles of zoological science.

1. Amœba introduces us to the idea of the cell—the structural unit of living organisms—consisting of a mass of protoplasm including a nucleus. Whereas,

when amœba undergoes fission, the two daughter cells separate and lead their own solitary lives; in the more complex creatures, on the other hand, which begin their existence as a single cell, the result of repeated fission is not a number of independent cell individuals, but a mass of cell individuals which continue to cohere together and form the co-operative cell community constituting the body of the animal.

2. We learn from amœba that the nucleus plays an essential part in the living activity of the cell. Such living activities as secretion are dependent on it. In fact, we may regard the nucleus as the part of the living substance of the cell in which is centred control over its living activities in general.

3. By studying the process of feeding and its sequels we recognize that living protoplasm is the seat of complicated processes of chemical change, the exact nature of which is almost entirely unknown, but which are for convenience grouped under the name "metabolism." Further, it is recognized that these processes may be grouped under two main heads: (*a*) processes involved in the building up of new living substance out of simpler, non-living substance—these are termed anabolic processes; and (*b*) processes involved in the breaking down of living substance into simpler, non-living, waste products—such processes are termed catabolic.

In a living animal the anabolic and the catabolic processes roughly balance one another. If the anabolic predominate then we find growth taking place. If, on the other hand, catabolism predominates, we have shrinking in the amount of living substance, which normally produces evident diminution in size. This latter, however, is not invariable, for the diminution in the amount of living protoplasm may be accompanied by the laying down within it of bulky, non-living substance, which may mask the diminution in amount of the protoplasm and even produce an actual increase in bulk.

As already indicated, we are quite in the dark as to the intimate nature of the processes of metabolism. Of the observable phenomena which accompany them, the chief is the taking up of oxygen and the giving off of carbon dioxide. In other words, the metabolism of living substance involves what may be called a slow process of combustion—not sufficient to produce smoke and flame—but sufficient in many of the higher animals to maintain a "blood-heat" distinctly above the temperature of the surrounding medium.

4. Finally, an important point to note is that the food of the amœba must contain proteins; it, like all typical animals, is quite unable to obtain its supply of nitrogen from simple salts, such as nitrates, as is the case with plants.

It will be remembered that the full name of the amœba described is *Amœba proteus.* This is an example of the ordinary system of nomenclature used by zoologists and botanists, what is termed the binominal system of nomenclature, developed especially by the great Swedish naturalist, Linnæus. This system may be illustrated by animals more familiar than amœba; for example, by the various species of cats. These, from their general resemblance to one another, are placed together in one group, termed a genus, and are given a generic name, *Felis,* common to them all, while each particular kind or species is given a specific name; thus, *Felis leo,* the lion; *Felis tigris,* the tiger; *Felis concolor,* the puma; *Felis onça,* the jaguar; *Felis catus,* the ordinary wild cat. A zoologist referring to any species of animal uses this system of nomenclature; for example, a tiger he refers to as *Felis tigris* or *F. tigris.* Any other zoologist then knows at once what animal is referred to, the scientific name being the same in all countries, whereas the same popular name may be applied to quite different animals in different countries. Thus in South America the name tiger is applied to the jaguar, lion to the puma, and crow to a variety of birds quite different from our crow.

In the case of the genus *Amœba,* too, various other species are known in addition to *A. proteus*, and distinguishable from it by differences in size and shape—particularly the form of the pseudopodia; also in habits—some inhabiting the sea, others damp earth, and so on. Amongst these, one set of species—often grouped together as a distinct genus under the name *Entamœba*—are of special interest from the fact that they inhabit as parasites the bodies of other animals. In the body of man himself a number of species of such parasitic amœbæ occur. *E. gingivalis* is a small amœba commonly found creeping about in the mouth, particularly in the neighbourhood of teeth that are not kept properly cleansed; *E. coli,* on the other hand, is common in the large intestine. Both of these amœbæ are comparatively harmless so far as is known: they may even play a useful part by devouring bacteria and similar intruders. A third species, however—*E. histolytica*—also inhabiting the intestine of man, while in normal circumstances apparently doing no particular harm, is liable on occasion, especially in warm climates, to become a cause of disease and even danger to life. In such cases it is found burrowing into the wall of the intestine, destroying it in parts, producing ulcers, and causing the disease known as amœbic dysentery. Or again, it may bring about localized destruction (abscesses) in the liver, brain, or other organ.

As has been mentioned, there are species of amœba which occur in the earth, and there is some reason to suspect that these, when they multiply unduly, become an important factor inimical to the fertility of the soil owing to their wholesale destruction of the bacteria upon which many of our crops are dependent for their supplies of nitrogen.

CHAPTER III

A MORE COMPLEX ANIMAL

THE amœba is a microscopic blob of living substance; it is instructive to compare with it one of the more complex animals in which the amount of living substance may weigh many pounds and the dimensions may be measured in terms of feet. Such relatively enormous organisms are seen in one of the main branches of the animal kingdom (vertebrata), that to which we ourselves belong, together with such creatures as fish, frogs, reptiles, and birds, as well as the lower mammals. As it is important to avoid being led away from main features into unimportant details, it will be best to deal simply with "a vertebrate" rather than with any particular kind of vertebrate. It should be said, however, that the general plan of vertebrate structure is most readily apprehended in practice by the investigation of one of the simpler, more lowly organized, vertebrates, such as, above all, the relatively archaic type represented by the shark-like fishes. It is for this reason that one or other species of dogfish—which are simply small sharks—is commonly used in university laboratories to introduce the student to the general plan of vertebrate structure.

The first point to notice about the vertebrate in comparison with amœba is that the unicellular stage is merely temporary. By successive processes of fission there are produced from it, not a population of separate, independently living, cell individuals, but a mass of cell individuals which remain cohering together, forming a vast cell community composed, it may be, of millions of cells.

The mere size of the mass of living substance that arises in this way involves practical difficulties which would make existence impossible were they not countered by new developments, involving specialization of individual cells for carrying out more efficiently the various living activities. In the first place, a mass of living substance the size of an elephant or a mouse would collapse were it not that the cell individuals along certain tracts become specialized for the formation of a supporting skeleton. Associated with the skeleton, other tracts of cells develop a greatly increased contractility—forming muscles which, attached to the skeleton at each end, are able to bring about movements of the various parts of the skeleton on one another and so produce movement of the body as a whole. The proportion of surface to bulk of body is, of course, quite inadequate to carry out the functions which it performed in amœba—absorption of food, water, and oxygen, and getting rid of fæcal material, water, and carbon dioxide and other waste products. Accordingly we find that with increase in size, a great extension of surface takes place, part of the external layer of the body growing inwards to form the lining of a spacious cavity and becoming specialized for carrying out certain of these functions particularly efficiently. In some of the simpler types of animal—such as polyps and sea-anemones—the cavity so formed ends blindly, but in all the larger animals, including vertebrates, it has become tubular in form (alimentary canal), with an opening at each end, one (mouth) for the ingestion of food, the other (anus) for getting rid of fæcal material. The process of respiration—*i.e.* the interchange of oxygen and carbon dioxide with the external medium—is in many of the more complex animals concentrated in particular bits of the external surface which undergo a great increase in area—bulging outwards into the surrounding medium (water) as gills, or inwards into the interior of the body as lungs. In the vertebrates, however, this respiratory process is very characteristically concentrated in the headward section of the alimentary canal (pharynx) from which there grow out on each side a series of pouches (visceral pouches) which, at their outer ends, fuse with the skin and open to the exterior, forming a series of visceral clefts, or gill clefts, on each side. The side walls of these clefts are very richly supplied with blood, they undergo an increase in area by growing out into flattened plate-like gill-lamellæ, and they form the organs by which fishes are able to carry out respiratory exchange between their blood and the water passed out through the clefts. In the terrestrial vertebrates, also, the respiratory apparatus has to do with the pharynx, but here it takes the form of a blindly ending pocket which grows out from the floor of the pharynx a little farther back than the gill clefts. This pocket-like outgrowth, which bifurcates into two lobes—a right and a left—is the lung, and the respiratory exchange takes place between the blood circulating in its walls and the air with which it is filled from the exterior. Fascinating chapters in vertebrate zoology have to do both with gills and lung. One of these deals with the fact—an inexplicable mystery until illumined by the light of evolution—that the higher terrestrial vertebrates, which will never at any time have occasion to use gills, yet develop their outfit of gill pouches in the embryo; another with the fact that in the modern highly evolved type of fish, represented by our ordinary food-fishes—such as cod or salmon—the right lobe of the lung has become evolved into an air bladder, with an elaborate mechanism for keeping the fish at precisely the same specific gravity as the water in which it is swimming, and so saving expenditure of muscular energy in order to keep at one level in the water; still another with the possibility that the original vertebrate breathing organs were neither gill clefts nor lung, but a series of branched external gills projecting from the sides of the body.

In amœba we saw that the living protoplasm manufactured or secreted various substances. Some of these, such as carbon dioxide or calcium phosphate, are merely excretory products—that is to say, waste products; others, such as the acid or digestive ferment secreted into the food vacuole, have a definite function. So also with every individual cell of the body of the more complex animal; it, too, forms its secretions, some useful, some worthless.

These cells, even in the body of a terrestrial creature, may be said to lead an aquatic existence, for they are all kept moist by the watery fluid which permeates the whole body and forms a kind of " internal medium," comparable with the external medium which surrounds the body as a whole. The internal medium, with its myriad cell inhabitants, is, of course, not pure water, any more than is the case with the water of a pool crowded with aquatic creatures. The various members of the cell community pass into it the products of their living activity, differing in different types of cell—it may be useful nutritive substances, the products of digestion of food material in the alimentary canal; it may be simply useless waste products or it may be substances which are waste so far as the cell producing them is concerned, but which yet play a useful part in stimulating or affecting in some useful way other cells of the body. Not only are varied substances being constantly discharged into the internal medium; there are also constant withdrawals taking place from it. Oxygen and substances useful as food are extracted from the internal medium by all the cells, while certain of the cells are specialized for the extraction of the poisonous· excretory materials from the internal medium and their transference to the drainage system of the body, by which they are passed away to the exterior.

While probably every type of cell in the body is more or less peculiar in its give-and-take relations to the internal medium, there are particular sets of cells which are highly specialized in relation to such activities. These are what are termed gland cells; their function is to manufacture, out of raw materials absorbed from the internal medium, particular types of secretion which are of use in the animal economy. Thus, in the skin of fishes are gland cells which produce a slippery slime to diminish skin friction with the water; in the skin of mammals are sweat glands, whose watery secretion, by the cooling effect of its evaporation when spread over the surface of the skin, plays an important part in regulating the body temperature. Again, in the lining of the alimentary canal are innumerable gland cells, the secretions of which play various parts in the process of digestion.

It is very usual for gland cells to be aggregated together to form glands, each possessing a tubular duct by which its secretion finds exit. Thus, in the case of the alimentary canal, besides the gland cells distributed all over its lining, we find special aggregations of these in particular regions. In the case of terrestrial animals there are commonly present salivary glands, the secretion of which, while serving primarily to moisten the food and keep the lining of the mouth from becoming dry, may take on other functions, such as initiating the process of digestion by turning starchy food into soluble sugar, or serving defensive or offensive purposes, as in the case of the poison glands of certain snakes. Again, farther back on the course of the alimentary canal are the important glands called liver and pancreas. Of these, the liver, the secretion of which was probably originally concerned mainly with the digestion of the food, is remarkable for the enormous size which it reaches in ordinary vertebrates and for the multiplicity of the functions which it has assumed. Its secretion, the bile, still plays a part in digestion, serving, in particular, to cause fats to pass into a condition of solution so as to be readily absorbed by the cells of the intestine, but its most conspicuous functions are of quite different nature. It plays a part in excretion, the pigments which give the bile its characteristic green or brown colour being waste products produced by the breaking down of the red colouring matter of the blood. It serves, again, as a great reservoir for carbohydrate food material, this being stored up in its cells, after a meal, in the form of glycogen, or animal starch, and then doled out continuously in the form of sugar for distribution through the body to meet the carbohydrate needs of the living cells. In connection with protein food the liver also plays an important part, the poisonous ammonia produced in the digestion of protein being converted by the liver cells into urea—a type of excretory substance which is eliminated from the body by the kidneys.

The other great gland connected with the alimentary canal—the pancreas or sweetbread—is less bulky than the liver but equally important. It plays the chief part in the digestion of the food, the secretion which it pours into the intestine containing at least three digestive ferments—one (tryptic) concerned with the digestion of protein, another with the digestion of carbohydrate, another with the digestion of fat.

The "give and take" relations of glands and other cells to the internal medium have been referred to. In the production of the ordinary secretion of a gland it is obviously the "take" relations that are specially concerned; the gland cell takes up certain substances from the internal medium and uses them as raw materials out of which to manufacture its own particular secretion. It will have been gathered, however, from what has been said of the liver that the "give" relations may also be of great importance; the sugar and the urea manufactured by its cells are not passed away into the alimentary canal by its duct, but are passed back into the blood as an "internal secretion." So, also, in the case of the pancreas. The obvious secretion—the pancreatic juice, with its ferments—passes into the intestine by the duct, but an obscure internal secretion containing the substance known as insulin is passed back into the blood and so distributed all over the body. This insulin is of the greatest importance to the welfare of the body, for unless the proper proportion of it be present in the internal medium, the living cells, as it were, lose their appetites for carbohydrates and are unable to assimilate the carbohydrates necessary for their healthy nutrition.

In some cases, such as that of the thyroid gland, which originally opens into the alimentary canal near the front end of the pharynx, the duct of the gland which is originally present becomes obliterated, while in still other cases, no duct is ever present. In such ductless glands or "endocrine" organs, it is clear that the "give" relations to the internal medium are dominant, the entire secretion being passed back into the internal medium and influencing its composition.

It will be readily understood that the concentration of particular vital functions in particular parts of the body necessitates an elaborate transport system, by which, on the one hand, products manufactured in one organ, but required by the cells in general, may be distributed, and, on the other hand, harmful substances, produced throughout the body, may be collected and brought to the organ concerned with their elimination. Such a transport system is provided by the blood in its vessels.

The blood is simply a portion of the watery internal medium confined within a branching system of tubular vessels, with cellular walls reinforced over most of their extent by a sheath of muscle fibres, by which their calibre can be varied. The ultimate twigs of the branching vessels pass into a network of very fine capillary vessels, the walls of which are so thin as to form merely a film of protoplasm through which diffusion can readily take place between the blood inside and the ordinary internal medium bathing the cells outside. It is here in the capillary network that the active interchange takes place. In the case of the vertebrate, one of the two main longitudinal vessels of the body, lying underneath the alimentary canal, becomes enlarged just behind the pharynx and its muscular coat greatly thickened and rhythmically contractile. This enlarged bit of vessel is the heart. Its rhythmic contractions pump the blood through branching systems of arteries to the capillary network, from which it drains back to the heart through the veins. Varying states of activity of different organs necessitate variation in their supply of blood. Brisker circulation in the body generally is brought about by more active heartbeat, while local variations in the circulation are governed mainly by variation of the calibre of the smaller arteries. An important part is played in this by the secretion (adrenalin) of one of the ductless glands, the muscular coat of the arteries being extremely sensitive to variations in the amount of this substance in the internal medium.

While the blood is primarily a watery fluid, it becomes at an early period of development populated with cells—the blood corpuscles. Some of these —the leucocytes, or white corpuscles—are like little amœbæ. They are not absolutely imprisoned within the vessels, for they often creep through the walls of the finer vessels and wander away in the internal medium beyond the vessel walls. These leucocytes play a great part in policing and scavenging the body, falling, in particular, upon hostile microbes that may have gained access to the body and destroying them. They constitute one of the great defence forces of the body against disease-producing microbes. The internal medium in the various chinks of the body outside the bloodvessels, and peopled by these amœboid cells, is generally known as the lymph, in contradistinction to the blood which lies within the cavities of the vessels. The blood is in the vertebrates distinguished from the lymph by its red colour. This is due to its containing numerous cells which, originally, like the leucocytes, have become specialized and different; they have lost their amœboid form and have become rigid discs, elliptical in outline, except in mammals, where they are circular. Their main characteristic, however, is the colour which gives them their name of red corpuscles. The red colour is due to a complicated iron-containing compound called hæmoglobin, which possesses a peculiar affinity for oxygen, combining with it to form oxyhæmoglobin of a brighter red colour

—a loose union, however, for the oxygen is easily separated again from the hæmoglobin. These red corpuscles are little vehicles for the transport of oxygen. As each corpuscle circulates through the respiratory organ, gill or lung, it takes up its load of oxygen, which combines loosely with the hæmoglobin. Whirled onwards in the blood-stream, the corpuscle eventually comes into the neighbourhood of cells hungry, as it were, for oxygen; there it gives up its oxygen, and the corpuscle, with its darker-coloured reduced hæmoglobin, is carried back towards the respiratory organ where its load of oxygen is again replenished.

While the oxygen is thus carried in special little vehicles, other substances are simply transported in solution in the blood. And it is not merely material substances which are transported by the circulating blood, for the same applies to heat. In a warm-blooded animal, the heat produced in parts of the body where active oxidation is going on is distributed throughout the body by the blood-stream, so that even those cells in remote and exposed positions, as on the surface of the body, are kept at a proper temperature.

It is only of recent years that the importance of the internal medium, and of the circulating part of it in particular, in regulating and co-ordinating the various activities of the body has been properly appreciated. Slight divergences from the normal in the composition of the internal medium bring about in the healthy body appropriate reactions. Thus a very slight increase in the amount of carbon dioxide in the blood at once brings about an increased activity of the breathing movements by which this is corrected. Similarly, a slight increase in the amount of an obscure substance called secretin, induced by the passage of food into the intestine from the stomach, at once brings about an increased flow of the pancreatic secretion required for the digestion of the food.

While such slight departures from the normal composition of the internal medium play important parts in regulating physiological processes in the bodies of the more complex animals, more marked departures from the normal are liable to upset the living activities of the body and so produce a condition of disease. For example, failure on the part of the pancreas to contribute its proper quota of its peculiar internal secretion (insulin) to the internal medium interferes in some obscure fashion with the absorption of carbohydrate food material by the cells of the body, with the result that this carbohydrate—duly doled out by the liver into the blood-stream for distribution throughout the body—simply accumulates in the blood and finally drains away to the exterior by the kidneys and is lost, thus producing the wasting disease known as diabetes.

In minute creatures like an amœba, the various parts of the protoplasmic body are clearly knit together into a single individuality, living impulses passing readily all through the protoplasm. In the larger animals, where the body consists of myriads of differentiated cells, the union of all its parts into one singly acting individual becomes still more necessary, but, at the same time, immensely more difficult owing to the greatly increased distances between its parts. A certain amount is done towards keeping up this union by the ceaseless stream of circulating blood, but an at least equally important part is played by the nervous system, consisting primarily of strands of living substance highly specialized for the transmission of impulses between different cells of the body. So highly specialized for their particular function are these nervous strands that we may take it that by their means living impulses pass as readily through distances measured by feet in the body of a large animal as they do through the minute fractions of a millimetre in the simple protoplasmic body of a microscopic creature.

The nervous system is concerned not merely with keeping up the close linkage of the different parts of the body into one functional whole; it is also concerned with the reception of impressions from the external world and with the carrying out of appropriate responses to these impressions. Scattered about upon those surfaces of the body liable to receive impressions are individual sensory cells specialized for this purpose. Such cells have, normally, one part of their protoplasm specialized for the translation of changes in their environment into terms of living impulses, which they forward along the nerve strands to the appropriate parts of the body. In the majority of cases these specialized receptive portions of the sensory cells are in the form of minute sensory "hairs"—little bristle-like projections of the protoplasm beyond the external surface of the cells. In some cases these sensory hairs are affected specially by chemical change in the medium in contact with them; that is the case with such as are concerned in the senses of smell and taste. In other cases, the sensory hairs are affected by mechanical disturbance, as in the senses of touch and hearing. Conspicuously different from other sensory cells are those concerned with the reception of light. In this case, part of the protoplasm of the cell takes the form of a clear transparent "rod," and it is apparently this which is sensitive to the impact of light waves.

While the nervous system is equipped at the periphery with these receptive sensory cells, it is also equipped with the means of bringing about active response on the part of the body. Certain of its strands (motor nerves) are continuous with muscles, and carrying impulses to these muscles cause them to contract and so bring about movement of the body; others are connected with other portions of the body and transmit impulses which rouse them into activity.

Finally, in the central parts of the nervous system are "ganglion" cells, which have to do with receiving the impulses that come in from the sensory cells and making the appropriate response in sending on the impulse, possibly in modified intensity, to the muscle or other organ which carries out the visible reaction.

The two remaining systems of organs, the excretory and the reproductive, are closely linked together. The gonad, the mass of reproductive cells, is, in the majority of animals, situated in the lining of the main cavity of the body known as the cœlome. The gametes when fully developed are shed into that cavity and find their way out of the body through slender tubes opening at their inner ends from the cœlome by a funnel-like opening. These tubes, arranged primitively in a row down each side of the body, are concerned primarily with the excretory function; they serve, on the one hand, to get rid of nitrogenous waste products, such as urea, which the cells of their walls extract from the circulating blood, and, on the other hand, to drain away superfluous watery fluid from the cœlomic cavity. In such an animal as an ordinary worm these excretory tubes are separate, one behind the other, but in vertebrates the individual tubes, increasing enormously in length, become entangled together to form a solid compact organ—the kidney.

It is some of the headward members of this series of excretory tubes which in the vertebrate serve for the passage of the gametes or reproductive cells. In the female sex a single one becomes greatly widened and forms the inner end of the oviduct, the wide tube through which pass the macrogametes or eggs. In the male, the arrangement is different in correlation with the much smaller size of the microgametes. These, instead of being shed into the main cœlomic cavity, in which they would be liable to wander away and be lost, are shed into a special isolated portion of the cœlome, which forms a cavity of the testis, and from it they pass out by a number of modified excretory tubes, which, like that which enters into the composition of the oviduct, have entirely given up their excretory function.

CHAPTER IV

THE EVOLUTION OF THE INDIVIDUAL

THE animal normally begins his individual existence as a single cell, the zygote, formed by the fusion (syngamy) of two cells (gametes) derived one from each parent. In some of the simplest types the two gametes are exactly alike, but in the great majority of animals they have become markedly differentiated and specialized: the one (macrogamete or egg) possesses a store of capital with which to start the new existence, in the form of a relatively large protoplasmic body, often provided with an abundant supply of reserve capital in the form of stored up yolk—concentrated food material—and, in correlation with its large size and its burden of yolk, shows a sluggish and inert disposition with little or no capacity for movement; the other gamete (microgamete or spermatozoon) is, on the other hand, specialized in the direction of active movement. These microgametes are of relatively small size, but they are produced in much greater numbers; they have no supply of food yolk, and each consists of little more than a dense mass of nuclear material, propelled in the commonest type by a slender protoplasmic tail.

Not only are the gametes specialized along two different lines, the individuals that bear them are also in the great majority of cases specialized into females which bear the macrogametes and males which bear the microgametes.

The zygote, or to give it its old name, the fertilized egg, is the unicellular or protozoon-like stage of the new individual. It contains, although in invisible form, all the specific characteristics of the adult. This can be demonstrated by taking the zygotes of, say, three different species by marine animals, such as fish. These show no trace of the differences which mark off the adults from one another. Such differences as are observable between them are differences of a superficial kind, such as size or colour, which have no relation to features of the adult. Yet if the three zygotes are kept in sea-water under favourable though absolutely similar conditions, each zygote will proceed to unroll the various stages in its normal life-history, culminating in the adult with its complete outfit of specific characters.

Reference has been made to differences in size between different zygotes. These are entirely due to differences in size of the macrogamete or egg, the dimensions of the microgamete being quite insignificant in comparison. As regards actual size, the zygote varies between quite microscopic dimensions and a sphere of about 85 mm. in diameter, as in the case of the ostrich.

The difference in size of the two gametes, whose fusion produces the zygote, is of great importance in relation to heredity, for (1) the heritage derived from each parent must be brought into the zygote by the gamete from that parent, and (2) observation shows that the heritage from the two parents is, on the average, equal, or in other words, the two parents are, *on the average,* equally potent in determining the characters of their offspring. It follows, then, that heredity is not carried by the substance of the gamete as a whole, for the one gamete may be millions of times the bulk of the other. On the contrary, the material basis of heredity, whatever it is, must be some part of the gametes which does not differ markedly in amount in the two. The detailed study of the process of syngamy in some of the lower animals—above all, in a round worm, *Ascaris,* which is found as a common parasite in the intestine of the horse—has demonstrated what this substance is, namely the chromatin of the nucleus.

In the nucleus of an ordinary animal cell the chromatin normally shows no very definite arrangement: it may have the appearance of an irregular network. When a nucleus is about to divide, however, in the process of fission a striking change comes about, for the chromatin now condenses itself into distinct separate pieces, commonly rod-like in form, termed chromosomes. In any one species of animal these have a definite number in each nucleus: a number which may be as great as 168 or may be as small as 4, or even 2. When the number is large the size of the individual chromosome is naturally small, and its details difficult to make out, and accordingly those species in which the number is small are of the greatest value in working out the minute details of chromosome behaviour.

The number of ordinary chromosomes in the ordinary cells of the body is always even. This applies also to the original unicellular stage, the zygote, and it is obviously what is to be expected, seeing that the total number of chromosomes is made up of two equal sets contributed by the two gametes. In the case of the Ascaris, already mentioned, each gamete contributes two chromosomes, so that the number in the zygote is four.

During the successive processes of fission, constituting the segmentation or cleavage of the egg, each chromosome splits longitudinally into two halves, and of these one passes to each of the two daughter cells. It follows that each of these, and each of their descendants, possesses four chromosomes, just as the zygote does. And, just as two of the zygote chromosomes are of maternal origin and two of paternal origin, so with all the ordinary cells of the body—each contains four chromosomes, two maternal and two paternal. But we have seen that the nuclear material dominates the living activities of the cell; consequently we may say that the living activities of every cell of the body is under the joint and equal control of nuclear material derived from the two parents. Hence it is that there is no part of the body, however insignificant, which is free from the control of heredity.

The ordinary cells of the body possess, as has been said, a characteristic, definite, even number of chromosomes. But there is one obvious exception to this general rule—namely, the gametes, for as two of these have to combine to furnish the complete zygote with its normal even number of chromosomes, the gamete itself must contain only half that number. Consequently, each species of animal has two characteristic chromosome numbers: (1) the full or "diploid" number found in the ordinary cells, and (2) the half or "haploid" number found in the gametes.

The expression "ordinary chromosomes" has been used because one of the important modern advances in zoological science has been the discovery of special "sex chromosomes," which are related to the sex of the individual. In the simplest and very common type of case the cells of the male individual are found to possess a special little piece of chromatin, to which was originally given the name X-chromosome; in the cells of the female, on the other hand, there are two of these sex chromosomes present. When we turn to the gametes or reproductive cells we find in the female that *each* macrogamete, or egg, possesses one sex chromosome, which is what we might expect—namely, that the number of sex chromosomes is reduced to half the normal number, just as is the case with the ordinary chromosomes. In the male the condition is different. At one of the divisions which the sex cells undergo before they become mature gametes, the one sex chromosome (which, as we have seen, is present in all the ordinary cells of the male body) does not undergo the usual process of splitting and sharing between the two daughter cells, but passes over bodily into one of them. The result of this is that half of the daughter cells, and therefore half of the microgametes to which they give rise, possess a sex chromosome, while the other half have none. If one of the former fertilize an egg, the resulting zygote will contain two sex chromosomes, and this will apply also to all the ordinary cells of the individual into which it develops; in other words, this individual will be a female; on the other hand, a microgamete of the second type (without a sex chromosome) fertilizing an egg will give rise to an individual in which every cell will contain only a single sex chromosome, in other words a male.

Here, then, we have the immediate cause of the determination of the sex of the new individual; it is brought about simply by the mere chance which of the two types of microgamete entered into syngamy with the macrogamete in order to produce it.

In various animals divergences from what has just been described are found to occur; in many other cases what does happen is still quite obscure. But it is an immense advance in zoological science to have ascertained in definite clear cases that the determination of the sex of the individual is brought about by the fact that one set of the gametes is divided into male-producing and female-producing, differentiated from one another by observable peculiarities of their chromosome equipment.

Another important advance in modern zoology is the discovery in certain cases that the part of the living substance concerned with the perpetuation of the race

—*i.e.* what will become of the gametes—is set aside at a very early stage of development from the remainder, which enters on the paths of specialization leading to all the various types of cell individuals required to carry out the bodily functions of the adult. In technical language the gonad (the total mass of reproductive cells) and the soma (the rest of the body) become marked off from one another at an extremely early period of development.

This fact, which doubtless future investigation will extend to animal types other than the few in which it has been so far demonstrated, is of great general importance. It emphasizes the fact that the individual does not in the strict sense produce its own reproductive cells but rather inherits them. The portion of its body which constitutes its gonad is simply a part of the zygote—*i.e.* a part of the gonads of the two parents, and so also with the gonads of these parents in turn and their predecessors. There is thus opened to us an endless vista into the past, the substance of the gonad of an individual existing on the earth to-day being part of a continuous thread of living substance stretching back without a break to the first beginning of living substance. The soma, or body, of each individual represents a portion of this continuous strand, which becomes side-tracked, grows enormously in bulk, serves to shelter and transport and nourish the gonad in its interior, and finally comes to an abrupt end in death, its purpose finished, when it carries down with it in the crash such unused remains of the gonad as have not fulfilled their destiny of prolonging the living strand into the next generation.

Yet another important bearing has to do with a well-known phenomenon of inheritance—namely, that features in the individual which are innate, either received from his ancestors or arising "spontaneously," are liable to be passed on to the next generation, while, on the other hand, features impressed on him during his individual lifetime, from the zygote stage onwards, are not so transmitted. To take the simplest kind of case—and in our biological philosophy it is peculiarly important to resist the temptation to wander away from relatively simple phenomena, amongst others so complicated and obscure that there is constant danger of stepping unwittingly off the path of strict logic—that of a human individual with a variation from the normal number of fingers or toes. When this occurs spontaneously it is apt to turn up in some of the descendants; if, on the other hand, it is produced artificially—*e.g.* by the operation of a surgeon—it does not reappear in the descendants. Similarly with scars or other abnormalities impressed upon the body of the individual by some disease or other experience through which he has passed: they are not transmitted to the descendants. The truth of this statement is borne out by a vast mass of data provided by the study of man, against which it is absurd to adduce, as is often done, a few apparently discordant results of laboratory experiments.

Appreciation of the relations of soma and gonad, as outlined above, removes all mystery from the noninheritance of impressed characters; in fact, to those who have such appreciation, any statement, however plausible, of impressed features being inherited, simply suggests the need of careful search for errors either in actual observation or in drawing conclusions from observation.

The process of development of the zygote into the adult consists on the whole, as has been indicated, of repeated fissions by which the original cell individual grows into a vast community of cells. The details of this process vary greatly in different types of animal, and our knowledge of them constitutes the great subdivision of zoological science known as embryology. Already in the early phases of development differences are visible between different animal types, differences associated especially with the proportional amount of reserve capital in the form of yolk contained in the zygote. The yolk is, of course, dead substance, and if present in large amount clogs and delays the living activity of the protoplasm. As, further, the yolk when present tends to be concentrated towards one (the "lower") pole of the egg, the clogging and delaying effect is more marked there. Consequently, if an egg with a considerable amount of yolk is examined after the process of segmentation has made some progress, it will be seen that the cells into which it is divided are larger towards the pole richer in yolk owing to a smaller number of divisions having been completed in that region. In the largest eggs, such as those of birds, by far the greater part of the egg is so rich in yolk and so poor in protoplasm that it never segments at all, the process of division being confined to a small portion in the neighbourhood of the upper pole.

In a large number of animals of various kinds the result of the process of segmentation is the formation of a hollow sphere of cells known as a blastula, one side of which becomes in further development tucked inside the other, so as to form a cuplike gastrula, walled in by two "primary" layers of cells, the ectoderm and endoderm, and containing a cavity open to the exterior at one end. In this phase the individual agrees fundamentally with the adult members of the lowly group of animals known as the Cœlenterata, which includes sea-anemones and polyps of still simpler construction. In the more complex types of animals the primitive cavity becomes the tubular alimentary canal and the two primary layers of cells form respectively the outermost layer of the skin and the lining layer of the alimentary canal, while by far the greater part of the mass of the body is composed of new developments of cells between the two primary layers. Details as to the appearance of these intermediate cells and as to their further development must be sought in textbooks of embryology, but one or two points of general interest may be mentioned here. The chief of these is that the early stages in the development of an animal may be either of two main types—that of a larva or that of an embryo. The first of these names is used when the young animal lives a free existence, fending for itself. The name embryo, on the other hand, is applied to the young animal when it does not lead a free existence, but lives within the shelter of an eggshell or the body of the parent. Countless varieties of larvæ are found in the animal kingdom. Familiar examples are the fishlike tadpole of the frog, the wormlike caterpillar of a butterfly, and the grub of a beetle. Embryos similarly exist in great variety. Two primary characteristics they possess: (1) a shell or other protective envelope within which development takes place; and (2) an abundant supply of yolk, on which the embryo subsists until it hatches out and is able to obtain food for itself. Both of these features are clearly seen in the hen's egg. The egg in the strict scientific sense is the spherical yellow portion, the yellow colour being due to the colour of the yolk with which the egg is crammed, except over a little bit at the upper pole, where a disc of greyish or whitish protoplasm is seen. The egg, after growing to its full size in the ovary of the hen, travels slowly to the exterior by way of the tubular oviduct, and, as it does so, is enclosed in layers of secretion produced by the cells lining the oviduct. This secretion over a great part of the extent of the oviduct takes the form of a clear jelly—the albumen, or white. Nearer the opening it takes the form of a tough white shell-membrane; and in the final portion it takes the form of a creamy secretion of lime, which solidifies all over the surface of the membrane to form the rigid shell.

In many animals a more advanced type of embryonic development is found, in which, instead of the egg being "laid" at an early stage, it is retained within the body of the mother and leads there a parasitic existence, absorbing food and oxygen from the blood of the mother. Such is the case in the mammals amongst vertebrates—at least, in all except the two most archaic mammals existing in the world to-day — the Platypus (*Ornithorhynchus*) and the Spiny Ant-eater (*Echidna*) of Australia, which still keep up the old-fashioned habit of laying their eggs. In the ordinary mammal, such as a rabbit, a cat, or a human being, the embryo proceeds to a late stage of its development before it is brought forth by the mother. In such "viviparous" creatures as they are termed many interesting adaptations are found—two of the most conspicuous being that the protective shell being no longer necessary is no longer developed, and that the reserve supply of yolk is for the same reason no longer stored up within the egg. A result of this latter fact is that the egg of the mammal has shrunk back to the minute size characteristic of yolkless eggs. The egg of a human being is no more than about 1/125 inch in diameter.

Another interesting feature of these vertebrate embryos is that the bladder (allantois), which in the amphibians like the frog serves as the receptacle for the kidney secretion, becomes in the embryo greatly enlarged and converted into a thin membrane richly supplied with blood, which lies close to the inner surface of the porous shell and serves the purpose of respiration. In the mammals a still further modification takes place, for it becomes intimately united to the wall of the uterus, forming with it the placenta, in which not only does respiratory exchange of oxygen and carbon dioxide take place between the blood of the embryo and that of the mother, but also exchange of food and waste products—the former being absorbed by the placenta from the blood of the mother, while the excretory products pass in the opposite direction from embryonic blood to maternal.

CHAPTER V

THE EVOLUTION OF THE ANIMAL KINGDOM

ONE of the great problems of zoological philosophy lies in the question: How has the vast variety of animals living on the earth to-day and during past geological periods come about? Is every species the result of a separate creative act, or is the process of creation a continuous one—a process of gradual evolution subject to so-called natural laws? And if evolution be a fact, what are the general principles that govern the process?

It may be said at once that the fact of evolution must now be regarded as demonstrated, and in reaching this conclusion zoological science harmonizes with all the other sciences, in which the advance of knowledge everywhere results in the linking together under common formulæ or general principles, of phenomena which had appeared to be isolated and unconnected.

Embryology.—It has already been shown how the adult animal individual evolves by a gradual process out of the zygote, or fertilized egg, a single cell, which, if it continued as such instead of growing up into something looking quite different, would be classed by zoologists as a member of the group Protozoa. In a great number of different animals there occurs later the gastrula stage—already mentioned—a somewhat cup-shaped creature with an opening or primitive mouth at one end, leading into a simple cavity in which the food is digested, walled in by the two primary cell layers—ectoderm and endoderm. This stage, too, represents a well-known type of adult creature. If the gastrula remained a gastrula and lived a free existence it would be referred to the main group or phylum Cœlenterata, the group to which sea-anemones and polyps belong.

Suppose we are dealing with one of the more complex vertebrate animals—say a bird or a man—we find equally striking peculiarities in later stages of development. For a time there is visible on the sides of the neck a series of clefts or openings which are recognizable as the gill clefts by which, in the case of fishes, the function of breathing is carried on. As development proceeds these clefts, with the exception of the first one (spiracle), become covered in and hidden away by a backwardly growing flap recognizable as the operculum, which overlaps the corresponding clefts in an ordinary fish. The first cleft never develops an opening to the exterior. It remains as a blindly ending pocket of the wall of the pharynx, dilated at its outer end to form the tympanic cavity and closed in from the outer world by the tympanic membrane, or ear-drum, which vibrates in response to the waves of sound. The inner portion of the spiracle remains as a narrow tube—the eustachian tube—leading from the pharynx into the tympanic cavity. Physiologically, this serves to keep the air-pressure equal on the two sides of the tympanic membrane. Pathologically, it may serve as a channel by which dangerous microbes find their way from the throat to the tympanic cavity and the numerous recesses that grow out from it into the mastoid portion of the skull. Not only are the gill clefts present in the embryo of the bird or man, but the characteristic arrangement of large bloodvessels in the form of aortic arches, which in the fish serve the necessary function of providing the gills by which it breathes with an abundant supply of blood, is also present for a time in the embryo. The heart is for a time in the form of a simple tube, along which pass waves of contraction. The bony skeleton of the adult is completely absent in the young embryo. In its place the embryo possesses a simple elastic rod or notochord running along the back, and later on a more complicated skeleton of cartilage or gristle. Now, were a creature possessing these various characteristics not an embryo but an adult animal, any zoologist investigating its anatomy would recognize in it a member of the fish group. It would not be like any ordinary fish in external appearance, but science has shown that mere external form is not to be trusted, and that internal structure alone is the safe guide to an animal's real affinities.

The fact that a bird or a man should have in early stages of development these various fish characteristics is obviously an astonishing one. What is its explanation?

What is the explanation of *any* of the ordinary peculiarities of an adult animal? What is the explanation of our having five fingers or any other human peculiarity? Clearly the immediate explanation is the fact of heredity, the fact that we are descended from parents and farther back ancestors from which we have inherited the peculiarity in question. Heredity, however, dominates, not merely the adult stage, but the whole life of the individual. Consequently, if gill clefts, aortic arches, a tubular heart, a cartilaginous skeleton are present in the embryonic man or bird, they must have been inherited from the ancestors. But in these ancestors at some period or other the various structures must have been functional; at some remote period the ancestor of the bird or man was an aquatic creature breathing by gills, in other words, a fish.

The fact, then, that any one of the more complex animals undergoes this process of evolutionary change, implies that its ancestors underwent a similar racial, secular, evolution during past ages.

Similar results emerge from the consideration of the development of individual organs during the young stages of animals. The complicated arrangement of the main bloodvessels of any of the higher vertebrates—which is quite unlike that of fishes—is found to come about by a process of gradual evolution out of a primitive arrangement of vessels corresponding with that of a fish. The liver, a large, solid, complicated organ in an adult vertebrate, goes through a stage in which it is a simple pocket-like outgrowth from the alimentary canal—a condition found in the adult of the lowest and simplest of all vertebrates—*Amphioxus*. The muscular system of a human being, with its hundreds of muscles running in all directions and serving to bring about the complicated movements of the body and its parts, is seen in the embryo to develop out of a set of myotomes, simple blocks of longitudinally running muscle fibres arranged in series along each side of the body, just as are present in the adult fish and serve in it to produce the side-to-side bending of the body by which it progresses through the water. As already indicated, the arrangement of tympanic cavity, or middle ear, and eustachian tube evolves in the embryo out of the first of a series of gill clefts—although, of course, the higher vertebrates have no functional reason for possessing gill clefts, as they never breathe at any period of their existence by gills.

Both the body as a whole, therefore, and its constituent organs go through, during their young stages, a course of evolutionary change, and this evolution of the individual is only explicable as a repetition or recapitulation of a process of slow or secular evolutionary change during the past history of the race.

Recognition of this general principle led to appreciation of the fact that important information as to former stages of evolution is to be expected from the study of embryology, the science which deals with the pre-adult stages of animals. An immense amount of such information has been so obtained, but as embryological science has advanced it has been learned that its data have to be examined critically to avoid misinterpretation.

In the early days of Darwinism, when the evolution theory was forcing itself into general acceptance, numerous workers turned to the study of embryology to decipher its records of past stages of evolution. And this, while it led to the building up of the modern science of embryology, also brought out the fact that the embryological record of secular evolution is interfered with by potent disturbing factors. Of these the chief is adaptation to the peculiar circumstances in which the young animal develops. The adult creature shows, as will be emphasized later on, intimate adaptation to suit its particular mode of life and environment. Now, in the case of any of the earlier stages of its development, the environment and mode of life are commonly very different from those in which the corresponding ancestral stage was passed. For example, the fishlike stage in the development of one of the higher vertebrates is passed within an eggshell or in the body of the parent, nourishment being obtained by a process of absorption through superficial bloodvessels, breathing also being carried out by these same bloodvessels instead of by gills, the whole mode of life being, in fact, as different as possible from that of the actively moving free-living fish. Consequently, we find in the fishlike embryo that features directly adapted to the aquatic existence—such as the stream-line form, the scaly slippery skin, the respiratory tissue on the walls of the gill clefts—have disappeared, while, on the other hand, features adaptive to embryonic life have made their appearance—such as the immense store of yolk and the precocious enlargement of the urinary bladder (allantois) and its specialization for the functions of respiration and nutrition.

It is consequently now recognized that one of the chief tasks of the embryological investigator is the sifting out from one another of those features that may be safely accepted as ancestral, and those, on the other hand, which are more or less modern adaptations to the developmental environment.

PALÆONTOLOGY.—It is a fortunate fact for the zoologist that in many types of animals the soft substance of the body is supported by skeletal structures composed largely of mineral substances, such as calcium carbonate and silica, for in such cases the skeleton, if embedded in suitable mud or silt, may remain throughout the ages in more or less recognizable form as a fossil, though all the rest of the creature's organization disintegrates and disappears. Now, admitting the fact of evolution, it is clear that we may expect palæontology, the study of fossils, to provide us with records of the evolutionary history of the skeletons of animals. In such a group as the Arthropoda—including shrimps and lobsters, woodlice, sandhoppers, and so on—the skeleton is an external one forming a jointed armour coat fitting closely all over the body, so that the fossilization of the skeleton means placing on record the entire external form of the body. And even in creatures such as vertebrates, in which the skeleton is internal, its structure may often give important clues to the structure of the rest of the body. It will, of course, be realized that our knowledge of palæontology, however greatly it increases, must remain very incomplete, for the simple reason that only an insignificant proportion of all the fossil-containing rocks can ever be searched for fossils. Many of the most interesting known species of extinct animals, though in their day common and no doubt represented by millions of individuals, are known to us only by a single specimen! It will also be realized that with most animals the chance of entombment in such a way as to lead to fossilization is comparatively small; in most cases the animal's remains simply disintegrate and disappear. And, finally, it must not be forgotten that the formation of a skeleton of lime or silica itself marks a distinct advance in evolution and that the representatives of earlier stages have, as a rule, vanished without leaving any fossil record behind them.

It will be understood, then, that the geological record of evolutionary change is necessarily of a fragmentary kind and that our knowledge of it is also necessarily ridiculously incomplete. It is, therefore, a strikingly impressive fact that palæontology has already provided us with a mass of evidence which, even had we no knowledge of embryology, would afford convincing proof of the fact of evolution. Of this mass of evidence, the most striking consists of little paragraphs of evolutionary history which depict evolutionary change in skeletal structures in the most complete detail. Such, for example, is the paragraph, pieced together from large numbers of American fossils, which tells us of the evolution of the modern horse—that strange mammal specialized for swift movement on dry plains and for subsistence upon harsh grassy vegetation. The most distinctive peculiarities of the modern horse are (1) its large size; (2) its long legs with the main mass of muscle concentrated towards the upper end so as to give a short period to their pendulum-like fore and aft swing and so conduce to rapid movement; (3) its support on the extreme tips of its toes, ensheathed in the enlarged claw or nail forming the hoof; (4) the fact that there is only a single toe in each foot; and (5) the long prismatic teeth with prolonged growth to compensate for wearing down by the harsh grassy food. Now, the researches of American palæontologists have brought to light large numbers of extinct creatures which demonstrate in the most complete detail how the peculiarities of the modern horse have come about by a slow process of evolution. The story begins in rocks of early Eocene age with little creatures some twelve or thirteen inches in height, with five toes, of which the middle one is very slightly stouter than the others. Still in the Eocene period creatures appear in which the two outer toes have shrivelled away to almost nothing, being represented each only by a slender splint of bone. By the Oligocene period a larger size is reached, about that of a sheep, and the two outer toes of the three are decidedly smaller than the middle one. In the Upper Miocene and Pliocene periods the side toes have become not merely still smaller, but they no longer reach the ground, so that they must have been merely functionless vestiges. Finally, in some of the representatives of this same period the side toes have disappeared entirely but for a slender splint of bone on each side of the large middle toe. In other words, the true horse condition has now been reached.

What has been said refers especially to the evolution of the hind-foot, but fossils tell exactly the same tale of the fore-foot.

The tall prismatic teeth of the modern horse have their evolutionary history recorded equally completely by fossils.

Various other evolutionary paragraphs have already been deciphered from fossil remains, but, apart from them, palæontology produces other convincing evidence of evolution, such as, for example, fossils which serve to link together groups of animals that are to-day quite disconnected. Such a fossil is *Archæopteryx,* the oldest known bird, from the Jurassic lithographic stone of Solenhofen, a creature about the size of a crow which, while possessing feathers and the general form of a bird, shows other features which are characteristic, not of birds, but of reptiles. Thus, the jaws possess teeth instead of a horny beak, the tail skeleton is long and many jointed like that of a lizard, the "fingers" instead of being fused together are freely movable, with claws at their ends. In other words, *Archæopteryx* is shown by its skeleton to have been an intermediate link between reptiles and birds.

Lastly, if a general survey is made of known fossils, it is seen that during the course of geological time, as recorded in the successive rock formations, the animal population of the globe has undergone, as a whole, a slow process of change in which it has gradually approximated to that which we see on the earth to-day.

One very astonishing, and too often ignored, fact emerges from the study of palæontology—namely, that while it provides an undoubted record of evolutionary change, that record is confined to the closing pages or paragraphs of evolutionary history, for when we examine the fossils of the oldest known fossiliferous rocks we find amongst them creatures of such complexity of structure and such relatively high evolutionary development that we are forced to the conclusion that they mark a period of evolutionary time enormously more distant from the commencement of animal evolution than it is from the present day.

How long in years, or millions of years, is this stupendously long, though *relatively* short, period of time represented by the palæontological record we cannot judge, and the reader may be warned at this point to pay no attention to quantitative estimates of geological time. Such estimates are often made, and may have a plausible appearance, but they are never of real value, because it never can be made certain that all the factors essential to the calculation are known. Kelvin's estimates, based on flawless calculation, were rendered worthless by the discovery of an unsuspected factor—namely, the occurrence of radioactive substances as sources of heat in the earth's crust, and any other estimate is liable to the same fate.

Appreciation of this point frees the evolutionary philosopher from any anxiety regarding disquieting suggestions that have been made by various critics as to the length of time available for the past of evolution. For when one or other physicist of distinction has pronounced the dictum that according to his calculation the physical conditions which render the earth habitable by living things cannot possibly have extended farther back into the past then such and such a period, the biologist has felt an uneasy doubt whether the process of evolution, as he knows it, could possibly have been accomplished in that period. He refrains from attempting to time the rate of evolution in figures, but he does realize that the process is one of extraordinary slowness.

There seems no longer any reasonable cause for such disquiet; looking back into the eternal past we can see no finite limit to the period of animal evolution.

Still another superficial criticism of evolutionary philosophy loses all its force in face of the same consideration—the criticism that we do not perceive the species of animals undergoing perceptible evolutionary change before our eyes. The critic of this type fails to realize that the period of human life—nay, the period of human history—is but as an instant in the midst of eternity, and that it is consequently no more remarkable that species, on the whole, show no evolutionary progress as we watch them than it is to gaze out on a tumultuous ocean illumined amidst the blackness of night by a single lightning flash and see that all the waves are still and motionless.

While the demonstration of the fact of evolution comes from embryology and palæontology, there are other sections of zoological science which furnish strong corroboration.

COMPARATIVE ANATOMY furnishes us with numerous cases of functionless organs, the existence of which becomes understandable when they are interpreted as the vestiges of organs which in earlier times were actively functional, such as the tiny, useless, wing of the New Zealand running bird, the kiwi, or the short bony tail skeleton hidden away in the body of man.

One of the most important contributions which comparative anatomy makes to evolutionary science is in demonstrating the fundamental unity of structure in organs superficially different in appearance and different in their functions. For example, the hand and arm of a man, the fore-leg of a dog, the fore-leg of a mole, the flipper of a whale, the wing of a bat are organs which look very different and which serve very different functions. A human artificer set to work to construct separate tools for such different purposes as grasping, running, digging, swimming, and flying would clearly design them on quite different general plans. When, however, the comparative anatomist investigates the organs that have been mentioned he finds that they are all constructed on the same fundamental plan, with the same general arrangement of bones, muscles, nerves, and so on. This would in itself be a most astonishing fact; it becomes, however, no longer astonishing, but, on the contrary, just what is to be expected if all these various organs, instead of being created independently, have evolved out of one original primitive type of fore-limb.

Conversely, comparative anatomy displays to us remarkable and unexpected differences between organs used for the same function and which we should therefore expect to be built up on identical plans. A good example of this is afforded by the wing skeleton of (1) a bat, (2) a bird, and (3) one of the extinct "flying lizards" or pterodactyls. In all these there is a general correspondence in plan; in each case the general plan is that common to the various types of fore-limb already mentioned. There are, however, striking differences in detail. In the bat the wing consists of a membranous web between the slender and greatly elongated fingers. In the pterodactyl the wing is again a membranous web, but in this case supported between the side of the body and the enormously enlarged fifth finger, corresponding to the little finger of man. Finally, in the bird the fingers, reduced to the first three, are short and stout, and more or less fused together, so as to form a clumsy support to the web of the wing, which is, in this case, not a continuous membrane, but formed of the stiff flat quill feathers. Such differences would be in themselves simply astonishing and, indeed, mystifying, but comparative anatomy teaches us by the general structure of these three types of animal that bats are mammals, and that birds and pterodactyls represent two different types of modified reptile; and it follows that the three types, having branched off from the vertebrate stem at three different points, there is nothing remarkable in their common plan being modified by differences in detail.

Lastly, we have the existence in nature of what is often called the natural classification of animals—the fact that animals fall into natural groups united by resemblances in structure, demarcated from other groups by differences. Such groups are, for example, the ordinary recognizable " kinds " or species of animal, the individuals of each one of which all recognize as blood relatives descended from the same ancestors, different degrees of affinity being recognized as finding their expression in such groups as families, clans, races, and so on. Just as these go to constitute the whole species, so different species group themselves into genera, and these into groups of higher and higher order until we come to the animal kingdom as a whole, and evolution explains all this grouping as representing simply different degrees of blood relationship with varying degrees of remoteness of the common ancestor.

Here and there in the animal kingdom there turn up types of creature the true affinities of which are not apparent, even after close investigation. In such cases comparative anatomy sometimes provides a reliable clue, intermediate creatures being discovered which form a set of connecting links with some well-known group. Here obviously evolution provides an explanation of the facts—the connecting types being surviving relics indicating the route along which the outlying type has gradually diverged from the main group.

ZOOGEOGRAPHY, again, the science dealing with the topographical occurrence of the various species of animals over the earth's surface, provides innumerable puzzles which find their solution in the fact of evolution. Thus, for example, the fauna, or animal population of any peculiar type of environment, such as a swamp, or a desert, or a clump of forest in one of the great continents, may show resemblance to the fauna of a similar locality in one of the other continents, but detailed study shows this resemblance to be comparatively superficial and to be underlaid by far more fundamental affinity to the fauna of other parts of its own continent, even although the local environmental conditions are entirely peculiar. Clearly this is what is to be expected if the peculiar local fauna has simply arisen by a process of evolutionary differentiation from the ordinary fauna of its own continent.

When after accepting, as we must, the fact of evolution we proceed to tackle the problem of its how and why, we see at once that the raw material, so to speak, of evolutionary change is provided by the fact of variation. Living substance is in a state of constant change or flux, and one of the expressions of this state of instability is that no individual animal is precisely similar to others. Even in a family born of the same parents, and with exactly the same ancestral history back through all time, different members of the family are seen to have the individual peculiarities which enable us to recognize them. In other words, each individual, while repeating in a general way the characters of its parents, never repeats these characteristics in perfect detail. Or, putting the matter in still other words, inheritance is never absolutely complete; it is this failure to repeat exactly or to the same degree the characters of the parents that constitutes variation.

The question is: By what means have the comparatively small differences seen in variation been built up into the far greater differences characteristic of the secular evolution of different types of animals? The only purely scientific answer that has been given to this question is that of Darwin, according to which the great factor involved is the process which he termed natural selection. This name, based on analogy with the process of selection by which breeders of domestic animals or plants are able to bring about evolutionary change artificially so as to produce breeds that may differ enormously from the original stock, is a somewhat cumbrous verbal expression of an undoubted fact of nature. It is obvious that in the varying descendants, say, of a single pair of animals, some will be better adapted, some less well adapted, to their particular mode of life and to the particular environmental conditions amongst which they live. It is equally obvious that, on the average, the former will live longer and tend to leave a greater number of descendants than the latter. But, seeing that the features constituting more perfect or less perfect adaptation will tend to be transmitted to the offspring, the strains showing better adaptation will tend to dominate over the others, which will be constantly eliminated. The natural selectionist would say that there is bound to be produced in this way a gradual evolutionary progress of the race in the direction of better and better adaptation, and the out and out Darwinian believes that here is a cause of evolutionary change so enormously potent as to be capable, given time, of producing the vast evolutionary changes which we know to have taken place.

There have been since the birth of Darwinism many attacks upon it, especially on the part of literary or laboratory zoologists, but, nevertheless, it holds its own in the opinion of most naturalists, especially those who are experienced field naturalists. Natural selection, in fact, would appear, in the present writer's opinion, to be now firmly established as *the* great cause of evolutionary changes. He believes, however, that certain modifications in detail from the theory as originally enunciated and as commonly taught are essential.

It must be remembered that natural selection is interested in the fitness of the individual as a whole, and it is quite wrong, in discussions concerning its potency, to isolate particular organs and to reason about them and their "selection value," ignoring the fact that they are simply factors in the general make-up of fitness.

Again, it must be realized that the relations of the organism and its environment are subject to continual change. The environment itself is constantly changing, owing to slow alterations in climatic, physiographical, or biological factors, while the organism itself is liable also to change, altering its habits, its feeding-grounds, its breeding season, and so on. Hence, there is little weight in the criticism that natural selection would soon cease to be effective as a cause of further progress owing to a condition of perfect adaptation being reached. We have to regard the main action of natural selection as that of keeping the organism in adaptive touch with the fickle and elusive and constantly changing environmental relations.

Another important point to be borne in mind is that the selection of actual variations involves selecting the hidden hereditary tendency to form variations of that particular type, and that as a necessary consequence natural selection has a guiding influence upon variation itself, tending to give it a kind of inertia analogous to that which tends to keep a moving body from changing the direction of its movement.

A difficulty that seemed formidable in the early days of Darwinism was the danger of favourable variations being swamped by intercrossing with individuals that did not show the particular variation.

The seriousness of this danger is much less impressive nowadays that we know that heredity is in the grip of the Mendelian principle, which insures new variations being passed on in undiluted intensity to numerous descendants.

We also appreciate better nowadays how frequently a set of individuals, varying in a particular direction, may be sheltered from inter-breeding by isolation, not merely obvious isolation of a geographical kind—as, for example, on an island or in an isolated body of water—but also by the far more elusive physiological isolation—as, for example, by the adoption of a new habit, or a new breeding time—or the still more elusive psychical factors which restrain or encourage breeding between particular individuals.

Another difficulty which has been stressed is that natural selection can only account for features that are adaptive, features that play a distinct part in making their owner " fit " to survive. This difficulty, again, is less formidable than it once seemed. The advancement of our knowledge of living animals in their natural environment is constantly bringing to light the adaptive utility of their various peculiarities; so much so that we now realize that a very large proportion of the features characterizing different species of animals are really useful or adaptive.

Perhaps the section of zoology in which it is most easy to demonstrate the sway of adaptation is that which deals with the coloration of terrestrial animals. This most usually is of an obliterative character; in other words, such as to render the animal inconspicuous when in its normal environment. For example, the white belly of so many mammals is, along with the gradual darkening of the colour up towards the middle of the back, a device by which nature counteracts the varying brightness of the illumination falling on the animal from above, so as to flatten out the appearance of the animal and destroy its rounded relief. The strongly contrasted dark and light of a leopard, jaguar, giraffe, or zebra is a device for distracting the attention, when the animal is in a dim light, from the patch of continuous colour, the form of which makes the particular animal recognizable. It is a device of exactly the same nature as that used bv the housewife when she hangs in her window a white lace curtain. Such a curtain, even when of very open lacework, serves to distract the attention of the outside observer to such an extent that he does not notice the contents of the interior of the room. As the conspicuous whiteness of the curtain becomes dulled, so does its efficiency as an " obliterative " screen disappear.

Many animals show an extraordinarily close harmonizing of tint with their usual background, such as green locusts, mantises, and parakeets. On the lichen-covered bark of the trees in the great tropical forests lives a varied population of many kinds of different animals all tinted so as to resemble their lichen background so closely as to be detected with the greatest difficulty. The most striking of all such cases are those many species of insects which show what is termed mimicry, copying with the greatest exactitude the appearance of some other insect which is habitually avoided by insect-feeding animals on account of its unpleasant taste or smell or its possession of some potent defensive organ, such as a sting

While, as has been said, the coloration of animals is, as a rule, obliterative, there are notorious exceptions. In many of these the coloration, although very conspicuous, is nevertheless of adaptive value, for it is associated with some unpleasant feature, and thus serves as a distinctive label by which possible assailants soon learn to avoid it. Such are wasps and hornets, where the conspicuous colour is associated with the possession of a sting; and the skunk, where it is associated with the secretion of an evil-smelling fluid which is squirted at intruders. This principle does not by any means cover all cases of conspicuous colouring, but it has to be remembered that the pigments of animals are usually waste products deposited on the surface of the body—such as salts of uric acid—and that these often *happen* to be of bright colours, as is the case with so many other chemical salts, so that we are quite justified in attributing the bright colour of some animals to pure chance, without any special biological significance. A beautiful example of this is the red colour of many deep-sea prawns, which only comes into existence when they are fished up into the realms of daylight; for down in the dark depths which they inhabit there is no red light to be reflected from their bodies, and therefore they cannot possibly be red in their natural environment!

In the case of male birds, where the coloration is often brilliant as compared with the female, there is reason to believe that bright colouring is appreciated and admired by the females, and is thus a feature of selective value which natural selection (of the type to which Darwin applied the special term "sexual selection") will tend to maintain and increase.

Enough has been said to emphasize the fact that a very large proportion of the peculiarities which distinguish different kinds of animals from one another are adaptive or useful, and are therefore of the type which would evolve through the action of natural selection.

One of the most interesting advances, however, in modern zoology has been to make clear how all the various parts of the living body are linked together in close physiological relationship. Variations, say, in the internal secretion of some particular organ, bring about the most unexpected and astonishing changes in quite different organs. It follows, then, that when an organ evolves in some particular direction for adaptive reasons, the changes which it undergoes may induce changes in other organs which have no direct adaptive significance whatever. In this fashion, then, natural selection may become indirectly responsible even for evolutionary changes which are not in themselves adaptive.

CHAPTER VI

ZOOLOGY AND THE CITIZEN

A GROUNDING in zoology is becoming in these days more and more clearly recognized as a necessary foundation for professional training in those various professions which are concerned with the practical applications of biological science. In the curriculum of our great schools of medicine care is taken that the specialized training in the anatomy and physiology of man is preceded by a grounding in the general principles of these sciences as seen in the animal kingdom as a whole. And it is realized alike that the technical methods made use of by the physician and surgeon are to a great extent those into which the student is initiated when studying zoology, and that many of the greatest modern advances in medical science, such, for example, as the fuller understanding of inflammation, immunity, and the curative and preventative methods that have resulted from that fuller understanding, have been based upon investigations primarily zoological in their nature. The same applies to many of the great problems of public health. Many a tropical locality, which formerly deserved the title of "the white man's grave" through the deadly prevalence of malaria or yellow fever, has been made comparatively salubrious by measures undertaken on the strength of zoological investigations upon the insect carriers of these diseases. And, in fact, the whole aspect of public health work, especially in the warmer regions of the world, has been greatly modified by the realization of the immensely important part played by animal microbes and their animal carriers. It is not merely the personal welfare of man himself with which such enemies interfere: they play an important part also in damaging his crops and his livestock. In order to be able to combat successfully their harmful activities, detailed information is necessary as to the habits and life-history of such animal enemies, whether microbes, carriers of microbes, or insects, worms, or other creatures which attack directly. Such information is still sadly deficient, and consequently there is at the present time great need, particularly in the colonies and oversea dominions, for recruits to the public service, with the technical training necessary for advancing our knowledge of this side of zoology and for devising and carrying into effect remedial measures based upon it.

Agriculture, stock-raising, fisheries—in fact, the general problems of food supply, storage, and transport—are alike clamant for the aid of zoological science.

Apart altogether, however, from the need, becoming ever more obvious and generally admitted, of zoological training for those about to take up any of these specialized professions, is the question of its importance as part of the training of the ordinary citizen. It is as yet but dimly perceived that the immense changes which have taken place in human society during its evolution from the primitive tribe to the complicated modern state must, if catastrophe is to be avoided, involve equivalent changes in the education of its citizens. The primitive human community, like the primitive animal community or the primitive cell community, is composed of a small number of individuals, relatively unspecialized, and only loosely knit together—liable to separate entirely under the stress of circumstance. The modern state, on the other hand, like the highly evolved animal community or cell community, is composed of a relatively enormous number of individuals; these individuals are highly specialized for carrying out the various communal functions, and they are linked closely together by the bonds of law, custom, profession, and general social organization, so that the community forms a highly efficient unit able to hold its own among its fellows.

We do not find, however, that educational systems have kept pace in their evolution with the evolution of the community; the great changes that are seen taking place in regard to education are improvements in detail rather than modifications in general plan. In a primitive human community still in the nomadic hunting phase of its evolution the education of the young individual is devoted to fitting him for his ordinary everyday existence. It follows two main lines. The first of these is scientific: he learns to observe accurately and swiftly the phenomena of nature around him, and to reason accurately and swiftly on the basis of his observations. As he is a hunter, the particular natural phenomena with which he is specially concerned are those that have to do with wild animals and their habits—in other words, zoological phenomena. The other line which his education follows is that of his relation to other human beings, more especially to those of his own tribe—what we may term ethics. There is, however, in addition to this education of the ordinary member of the tribe the other education, which deals not with the natural but with the supernatural, in particular with the evil spirits that are the cause of disease and other misfortunes. This is the esoteric education of the "medicine men," so widespread a cult amongst primitive peoples.

These two types of education—the general and the esoteric—persisted long in the development of civilization. In our Western civilization the latter was centred especially in the great religious houses.

The fateful moment so far as modern education is concerned arrived with the invention of printing, which for the first time made the spread of education throughout the community feasible. It was now possible to multiply to any extent the stores of learning hitherto locked up in the rare and costly manuscripts of the religious houses. The natural results were two: (1) printing in its early stages emanated from and was controlled by the Church; and (2) the education spread by books was not the education of the ordinary man to fit him for his ordinary life as a citizen, but the esoteric literary type of education which had existed in the monasteries.

And so it remains to-day; education is mainly literary rather than scientific and ethical. The ordinary citizen is not even given a glimmering of understanding of those zoological principles which dominate social as well as individual evolution. And the ignorance of these principles, while it leads necessarily to an immense deal of discontent, unhappiness, and inefficiency, is capable of leading in the end to complete social disaster.

The traveller in the tropics occasionally finds himself in a wide-spreading plain dotted as far as the eye can reach with innumerable termite hills, each the home of a large and complex community of "white ants." If the day be favourable he may witness the swarming of the termites, when innumerable couples start off to form new communities. Of the vast number of potential new colonies so arising, only an insignificant fraction succeed in establishing themselves, taking the place of less vigorous colonies which die out. The naturalist in such circumstances has brought home to him the fact that there is a struggle for existence, a survival of the fittest, between animal communities as between animal individuals.

So also with human communities. Throughout our social evolution there has taken place a remorseless crushing out of the less efficient communities by the more efficient. The process—heart-breaking to those who love primitive man—may be seen still in full swing among the more primitive races to-day. Over great tracts of the two Americas the original inhabitants in their primitive stage of evolution—little tribes of unspecialized individuals only loosely linked together—have been entirely crushed out of existence when the more highly evolved old-world type of community came into competition with them; in other districts they still linger on, where the competition has not yet reached its full intensity.

Training in zoology, and even an elementary grasp of its general principles, helps on the one hand to safeguard the citizen from being swayed unduly by the attractive idealism which assumes a universal unselfishness and ignores those deep-seated differences between different races and different states and communities—differences in material interests, in customs, in prejudices, in religious beliefs—which must remain potential sources of conflict and war until the day when man is freed from the nature engrained into him by the long and cruel and bloody past, during which he has climbed the evolutionary tree to his present dominant position.

But, on the other hand, such training also serves to drive home the ethical principles of citizenship. The citizen learns to realize that he is part of a great live evolving organism. He learns to appreciate to what an extent his own personal comfort and prosperity is dependent upon the health of that organism as a whole. Just as a single cell or organ of the human body is dependent for its welfare upon the health of the whole, and as that in turn is dependent upon each constituent cell or organ playing its part in the bodily economy honestly and efficiently, so also is he in like manner dependent upon the health of the social community, and that in turn dependent upon each set of specialist citizens carrying on their particular work industriously, honestly, and efficiently. Primitive man, sharing with his sparsely scattered fellows a relatively enormous tract of country, is dependent mainly on himself; by his own ability and industry he wrests directly from Nature the few necessities of his miserable existence. The citizen of the crowded civilized city or state, on the other hand, is entirely dependent upon his fellow-citizens. The *clothes he wears, the varied foods that are brought to* him from distant parts of the earth, the water and milk supply brought from the surrounding country, the means of transport which enable him to get to his work and his pleasures, the fuel that cooks his food and keeps him from perishing with cold, literature and the arts that minister to his instruction and entertainment, medical care that tends him when sick; these and everything else that make civilized existence possible to the individual citizen are made available to him by the intensely specialized industry and efficiency of his fellow-citizens. If the members of a particular industry which comes into direct relations with his daily life—such as transport, coal supply, or milk supply—cease their work, the citizen realizes quickly enough the extent to which his personal well-being is affected, but it takes a little zoological training to make him realize that slackness, inefficiency, idleness in general, are inimical to communal health and prosperity and consequently harmful to the personal comfort and prosperity of himself. The appreciation of such facts is of value not merely in emphasizing the importance in the education of the young citizen of developing habits of industry and the ambition to excel, but also the development of a proper sense of gratitude and duty towards the community as a whole and the fellow-citizens who compose it.

There are those who will criticize education along such zoological lines on the ground that it tends to limit personal liberty. This is undoubtedly true. To the citizen who shows a proper appreciation of what he owes to the community, who does his best to express that appreciation by carrying out smoothly and efficiently his daily work, who is of sufficient humility of spirit to realize that it is very likely himself who is mistaken when he finds himself in conflict of ideas with the general body of his fellow-citizens; to such a citizen the widest liberty would be accorded. But to the loafer, the person who thinks everyone "out of step" but himself, the fisher in troubled waters, the individual who drops sand into the bearings of the delicate communal machinery, the criminal; to all these the extension of zoological training will undoubtedly mean a restriction of personal liberty.

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AN INTRODUCTION TO BOTANY

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AN INTRODUCTION TO BOTANY

INTRODUCTION

It is the purpose of this book to acquaint the general reader with the scope of modern botany, to explain the nature of the problems with which botanists are concerned, and to indicate the bearing of this particular branch of science upon human welfare.

The Royal Botanic Gardens at Kew may be regarded as the botanical headquarters of the British Empire, and has done work of inestimable importance by introducing to various Colonies, etc., such valuable plants as rubber, quinine, bananas, tea, cocoa, coffee, dyes, fibres, timbers, etc. Recently Kew received a substantial grant from the Empire Marketing Board largely for assisting work of this kind.

Of recent years there have been many conferences and congresses of workers in the science of plants. In 1923, for example, an International Congress of Plant Pathologists was held in Holland, at Wageningen, the headquarters of research work upon potato diseases, etc., and was attended by some 30 Dutchmen and 65 workers from abroad, representing 25 nationalities and 30 Dominions and Protectorates. In 1924 an Imperial Botanical Conference was held in London, and brought together about 230 home botanists and over 60 from 25 different Dominions, Crown Colonies, and Protectorates, in addition to 10 visitors from America and Czechoslovakia. The Fifth International Botanical Conference has been arranged to meet in Cambridge in 1930, when the members will form no less than seven different sections in order to discuss related botanical problems.

Various great industrial organisations have now come to realise the vital importance of botanical investigations in connection with the raw materials, etc., with which they are concerned. Thus the Linen Research Association of Belfast has subsidised research on the flax plant, and many planters' and growers' associations employ botanists to study the physiology and the diseases of such crops as sugar-cane, tea, coffee, rice, and rubber. Perhaps the most active of all these is the Empire Cotton Growing Corporation, which, by means of adequate scholarships, etc., has for some years past been training promising young men in research methods with a view to fitting them for posts abroad in connection with cotton growing. Such developments are both natural and necessary, since plants, after all, are the basis of the world's food supplies and the source of much of its raw material.

CHAPTER I

THE SCOPE OF MODERN BOTANY

From time immemorial man has interested himself in plants, either as material for food, fuel, clothing, or shelter, or as the sources of many substances harmful or beneficial to his health. Even the men of the old Stone Age, some 50,000 years ago, appear to have had some sort of agricultural art. The Lake Dwellers of Switzerland, during the period 4,000-2,000 B.C., according to Dettweiler, cultivated three kinds of barley, five of wheat, two of millet, and one of flax.

Among primitive races those individuals whose knowledge of the properties of plants was above the average came to occupy the important position of "medicine man," as is still the case in uncivilised communities. When at a later age medicinal preparations were employed with more definite knowledge of their values, a real necessity arose for reliable means of identifying the plants from which the drugs were obtained. The first recorded writings of any real value on the nature of plants were the *Historia Plantarum* and *De Causis Plantarum* of Theophrastus of Eresus, a pupil of Plato and Aristotle, born in Lesbos in 370 B.C. Theophrastus, unlike so many who followed him, described plants from actual specimens, and seems to have had at least 500 different kinds of plants in the garden which he inherited from Aristotle. Theophrastus has been called the "Father of Botany," and, strange to say, for nearly eighteen centuries after his death no other botanical writings appeared, though agricultural treatises by Cato, Vergil, and others, and works on materia medica by Dioscorides and Galen, were produced during the following four or five centuries.

Botany saw no further advance till the time of Valerius Cordus, who was born in 1515, and became a lecturer in the University of Wittenberg. Instead of rehashing ancient descriptions of plants, Cordus, like Theophrastus, studied them where they grew and described them from specimens in flower and fruit. He recognised the nature of many plant organs, realised at least something of their more striking physiological significance, and even hinted at the mode of reproduction of ferns. About the same time William Turner, sometimes known as the "Father of English Botany," a much travelled collector, published his *History of Plants*, a descriptive work rather on the lines of the herbals of other writers.

During the sixteenth century the first University botanic gardens were founded. Italy led the way with those of Padua (1545), Pisa (1547), and Bologna (1567), and was followed by the Netherlands (Leyden), France

(Montpellier), and Germany (Heidelberg). In England the first step towards the foundation of the Oxford University Botanic Garden was taken in 1621, but it was not till after 1632 that the garden was actually installed. At Cambridge an attempt to establish a "physic garden" was made in 1696, though the garden did not materialise until 1762; it was transferred to its present site in 1831. Even in 1587 the College of Physicians had a garden, and the minutes of the College record that John Gerarde, the author of the famous *Herball* (1597), agreed to become its superintendent. The Apothecaries' Garden, now the Chelsea Physic Garden, on the Embankment, was founded in 1673, and Kew itself originated in a physic garden made in 1760 by the Princess Dowager of Wales.

From such beginnings grew the modern science of botany. Within the limits of this book it is impossible to trace in any detail the growth of our knowledge of plants. Here it must suffice to indicate the main divisions of the subject, and to point out the more conspicuous landmarks in its development.

STRUCTURAL BOTANY.—The advent of the lens enabled Robert Hooke, an Englishman, to publish his *Micrographia* (1665), in which, amongst many other things, he described the cellular nature of vegetable tissues. Nehemiah Grew, another Englishman, worked systematically on plant structure, and in 1671 an essay by him on that subject was printed by the Royal Society of London, which simultaneously received from the Italian Malpighi an independent account of similar observations. These two botanists laid the foundations of the science of structural botany, of which there are now several branches.

1. *Morphology* is concerned with external form and the organisation of the plant as a whole.

2. *Anatomy* involves the cutting up of the plant so that the cellular structure may be examined with the microscope. Hence, anatomy deals with cells and tissues and their disposition within the plant.

3. *Histology* includes the more detailed examination of the composition of tissues and cell walls, and needs higher magnifications as well as more careful staining and other preparation of the material for examination.

4. *Cytology* inquires into the very finest details of the cell contents and the structure of the living matter of the plant, and calls for the most skilful use of the highest powers of the microscope, together with a very elaborate technique.

SYSTEMATIC BOTANY has been helped by anatomical studies which have thrown much light upon the relationships of plants. Although Aristotle wrote about plants, nothing is known of his ideas on classification, owing to the loss of his special treatise on plants. Theophrastus grouped plants as Trees, Shrubs, Undershrubs, and Herbs, and it is a remarkable fact that practically no real advance upon this plan was made for the next twenty centuries.

During the sixteenth century attention centred upon the flower as a more satisfactory basis for the purpose of classification, although the old division into Trees and Herbs persisted with all but a few writers until the time of Linnæus (1707-78). The difficulty which faced the earlier botanists was the absence of any real clue to natural affinities. Little light was shed upon the problem till towards the end of the eighteenth century, when discoveries in other branches of botany revealed the paths along which systematists might try to make their way. Thus Koelreuter (*c.* 1760) and Sprengel (1795) discovered something of the true significance of the reproductive organs of flowers, though Nehemiah Grew had previously hazarded a shrewd guess, and Camerarius (1694) had made experiments upon castrated flowers. During the first half of the nineteenth century the life histories and reproductive methods of some of the non-flowering plants began to be understood, and the existence of sex in plants became firmly established.

The publication of Darwin's *Origin of Species*

(1859) setting forth the idea of the origin of all animals and plants from ancestral types by descent with modification, led to the formulation of schemes of classification reflecting the probable lines of evolution, with varying degrees of success.

Palæobotany, or the study of plant remains from the rocks, has yielded many a brilliant discovery which has helped to fill in some of the gaps in schemes of classification. Fossil plants had attracted attention in the Middle Ages, but not till the time of Blumenbach (1790) were sound ideas of their age put forward. Adolphe Brogniart was the pioneer palæobotanist, and he recorded his observations in his *Histoire des Végétaux Fossiles* in 1828. Shortly afterwards (1833) Witham, of Yorkshire, described the internal structure of certain fossil plants, and during the following two or three decades Gœppert, Unger, Corda, and others greatly extended the knowledge of fossil types and compared them with existing forms.

In England the possession of extensive coalfields led to the prosecution of many researches upon the plants of the coal measures. Williamson (1816-95) in particular devoted himself to such work, and Dr. Dunkinfield Scott, happily still pursuing similar studies, collaborated with him during his later years, and has himself greatly extended our knowledge of plants of the past. Much remains to be done before the story of the evolution of plants can be told in full, and it may well be that evidence for the actual existence of some hypothetical ancestors of our present-day plants may never be forthcoming. Lest it be thought that such studies are merely of academic interest, it is as well to record that the keen business men who direct the Lancashire and Cheshire Coal Research Association thought fit to establish palæobotanical laboratories at Bolton, in which the microscopic structure of plant remains from the various coal seams could be examined, and the precise nature and quality of the coal determined.

Vegetable Physiology, or the study of the functions of plants, naturally depended for its progress on the growth of knowledge in the related branches of science, physics and chemistry, especially "organic" chemistry. Nehemiah Grew, whose anatomical researches constituted so important a landmark in botany, did little in the way of discovering the purposes of the structures he described and drew so well. He did, however, extract the green pigment from leaves, and seemed to realise something of the use of the stomata or pores in the skin of leaves, as also did Malpighi. During the eighteenth century physics and chemistry made progress, and Stephen Hales (1677-1761) set forth some sounder notions of plant physiology. Hales' *Vegetable Staticks* (1727) was a remarkable work for the time, in that its author broke away from the traditional dependence upon the writings of the ancients, or on vague speculations, and devoted his energies to devising experiments, by which means he arrived at many new conclusions, especially with regard to the movements of water within the plant, and the nutritive processes carried out by leaves. Hales was, in fact, the founder of the modern science of plant physiology.

A great impetus to physiological botany was given by the discovery of carbon dioxide (Black, 1754, renamed by Lavoisier later), and of oxygen (Mayow, 1674, rediscovered by Priestley in 1774). Priestley's *Experiments and Observations on Different Kinds of Air* contained accounts of the action of green plants on air in sunlight, and paved the way for the important discoveries of Ingen-Housz (1730-1799), who, though born in Holland, spent much of his life in England. Ingen-Housz greatly extended the observations of Priestley, and arrived at an approximate understanding of the gaseous exchanges effected by plants.

Further progress in this branch of physiology became possible when Wöhler's discovery (1828) of the synthesis of " organic " from " inorganic " compounds rendered untenable the notions of " vital force " which prevailed. The early decades of the nineteenth century also saw the beginnings of the application of physical laws to plant processes. By degrees the outlines of plant chemistry were sketched in, and the first great agricultural chemist appeared in the person of Liebig, whose famous work on *Organic Chemistry* in relation to *Agriculture and Physiology* was published in 1840. The discovery of the nature and significance of the living matter in plants opened up new avenues of advance in physiology, and more botanists became interested in experimental as opposed to the older branches of their science. The chief sub-divisions of vegetable physiology are concerned with the absorption and transference of water and salts, growth, nutrition, reproduction and movement, and they involve considerable excursions into bio-physics and bio-chemistry. At present the chief task of the plant physiologist is to interpret living phenomena in terms of the properties of matter.

PLANT PATHOLOGY, or the study of disease in plants, is a branch of botany of obvious practical importance. The losses caused by diseases among agricultural and forest crops are incalculable, but some idea may be conveyed by a few figures and facts. Thus in 1845 the potato crop of Ireland was so severely devastated by the attacks of a fungus (*Phytophthora infestans*) that one of the worst famines ever experienced by the country followed. Tens of thousands of lives were lost, and terrible hardships were suffered by the whole population. In Prussia, in 1891, cereal losses due to " rust " fungi were estimated at over £20,000,000, about eight times the loss from similar causes in Australia during the same year. Huge losses have occurred in America from fungus attacks, which in 1919 accounted for 2 per cent. to 50 per cent. of the harvests. It is difficult to estimate the world's annual loss from such scourges, but it has been set by one authority at anything up to £300,000,000.

Trees are among the victims of this vegetable warfare, which has been waged with great vigour in the neighbourhood of New York. In 1904 chestnut-trees in that city began to die from a fungus which invaded their growing regions, where it could not be attacked. The disease spread so rapidly and with such fatal effects that in Brooklyn alone over 17,000 trees were exterminated, and scarcely a tree within a radius of nearly 200 miles of New York escaped destruction. In 1911 this fungus had robbed the country to the extent of some 25,000,000 dollars, and a special committee was set up to deal with its activities.

One more example of the damage caused by a fungus may be quoted. In 1869 disease appeared on the leaves of coffee in a plantation in Ceylon, and within four years scarcely an estate in the whole island was unaffected. The coffee planting industry was destroyed, and such was the ruin which resulted that the Oriental Bank collapsed. The trouble has since spread to every coffee-producing country of the Old World.

Plant plagues like these have called forth active combative measures, and in most countries now phytopathological services are supported, though not always as adequately as is desirable.

Little progress in plant pathology was possible until the foundations of vegetable physiology had been laid, and a knowledge of the life histories of bacteria and fungi had been gained. Hence plant pathology as a definite branch of science was inconceivable until towards the middle of the nineteenth century, when the illuminating researches of M. J. Berkeley, of Oundle, Rugby, and Christ's College, Cambridge, laid its foundations. He it was who cleared up the nature of the "potato murrain" in 1846, and by this and later researches revealed the true economic significance of the fungi. He was also a great systematic authority, and his wonderful collections of fungi from all parts of the world are to be found in the great Herbarium at Kew.

Diseases may be caused by mechanical injuries; by abnormal physiological conditions; by visible parasitic micro-organisms like bacteria and fungi, which invade the tissues, destroy the cells and absorb their food reserves; by animal and insect parasites; and by undetermined agencies, as in the infectious " virus " and " mosaic " diseases of beet, cabbage, corn, cotton, cucumber, hops, peach, potato, sugar-cane, tobacco, tomato, etc. Although tremendous strides have been taken in the domain of plant pathology, innumerable problems await solution, among which may be mentioned the whole subject of immunity, or resistance to disease. Needless to say, such problems bear closely on medical science.

PLANT BREEDING is another branch of botany which has an obvious bearing on human welfare, and one in which remarkable results have been achieved during the present century. That the offspring of plants, as of animals, both resemble and differ from their parents, is a familiar enough observation, and one which long ago led agriculturalists to select desirable types from which to breed. Various empiric rules came to be recognised, but no clear scientific principles became available to guide the breeder until the beginning of the twentieth century. By that time so much knowledge had accumulated upon the facts of variation and evolution that the late Professor Bateson introduced the term *Genetics* to cover those closely related portions of biological science which attempt to account for the differences and similarities presented by the descendants of common ancestors.

Early in the nineteenth century several prizes were offered by various learned bodies for theses on the value of hybridisation for the production of new varieties of useful plants, and similar topics. From experimental work initiated in this way it became clear that crossing often led to variability. In 1849 Gärtner published a prize essay, in which he detailed the results of thousands of carefully controlled crosses made with several hundred different species. He observed the common increase of vigour of hybrids, the fact that sometimes the offspring resembled one parent more than the other, and that in certain cases pigmentation characteristic of one parent dominated (appeared instead of) that of the other parent in the hybrids—*e.g.*, in the seed-leaves of peas. Naudin (1865) carried such work a stage further, and noted that while the first generation—*i.e.*, the hybrids—were uniform, the second generation, produced by intercrossing the hybrids, gave rise to many different types, some of which were indistinguishable from the parents.

It was, however, Gregor Mendel, an Austrian monk, who discovered, in a monastery garden at Brünn, the key which was to unlock many of the secrets of hybridisation and heredity, and who gave the world new tools with which to fashion desirable races of animals and plants. Mendel's results were published in 1865 in a rather obscure journal, where they remained overlooked until, curiously enough, they were re-discovered independently in 1900 by De Vries, Correns, and Tschermak. Thus was founded the sub-science of *Mendelism,* embodying among its fundamental principles the independent inheritance of corresponding pairs of parental characters, the dominance of one or other of each pair of characters in the hybrid, and the independent segregation of the members of each pair amongst the reproductive cells.

The whole outlook of the plant breeder, as well as that of the pathologist, has been changed since 1900, and the present century has already seen many valuable new types introduced into practical service—*e.g.*, cereals which are highly resistant to rust fungi, since such resistance, like many other valuable qualities, has been found to follow Mendelian laws of inheritance. From Mendel's work, too, has developed much of the modern science of *Eugenics,* which has as its goal the improvement of the human race.

While *Mendelism* has explained much, it has also raised many new problems. Moreover, it has been found, notably by De Vries, that among the offspring of some plants in which crossing has been prevented, new forms suddenly appear, which depart very definitely from the parental type, and breed true. Such forms, which appear to originate by a sudden jump, and not by the slow accumulation of minute differences, are known as *mutants,* and the phenomenon as *mutation.* Evolution is here discontinuous, instead of more or less continuous, and there can be little doubt that mutation has played a part in the origin in nature of new types. Many cytological studies of mutants have been made with interesting results, for which, however, recourse must be had to special treatises.

PLANT ECOLOGY, literally the study of plants in their homes, is practically a product of the present century. During the nineteenth century our knowledge of the geographical distribution of plants increased rapidly. One of the most active workers in this field, as in several others, was Robert Brown (1773-1858). Early in his life he made the acquaintance of the famous explorer, Sir Joseph Banks, through whom he secured an appointment as naturalist to the *Investigator* (1801), and visited Australasia, where he made extensive plant collections. On his return he set to work to describe the flora of the areas he had visited and compared it with those of South America, South Africa, and other regions.

Such work was extended greatly by Darwin's friend, Sir Joseph Hooker (1817-1911), who at the age of 22 joined Sir James Ross in a long expedition to the extreme southern seas, from which he gathered material for his first great work, *The Antarctic Flora.*

Hooker next explored the Himalayas and gave an account of his geographical and biological experiences in the *Himalayan Journals* (1854). Other regions visited by this great plant geographer included Syria, Palestine, Morocco, and much of North America. To Sir Joseph and his father, Sir William Hooker, Kew owes much of its prestige, for it was the father who really created the museums and herbaria, and the son who enriched them with his own superb collections, while both, as Directors, developed Kew as a great scientific institution.

Attempts to relate the present distribution of plants to the conditions of their environment, and to their structure and mode of living, followed naturally from the rapid development of experimental plant physiology, largely under the influence of Julius von Sachs, whose *Handbuch der Experimental-Physiologie der Pflanzen* (1865) did so much to spread interest in work of that kind. Similarly the attention of anatomists began to be directed towards the study of the functions of cells and tissues, especially after the appearance of Haberlandt's *Physiologische Pflanzenanatomie* (1884).

The first general account of vegetation from the point of view of the structure, development, and relationships of *plant communities* appeared in the *Plantesamfund* (1895) of E. Warming, of Copenhagen, who has lived to see an extraordinarily vigorous growth of the science of plant ecology which he founded. Very shortly afterwards A. F. W. Schimper published his stimulating *Pflanzengeographie* (1898), an illustrated description of plant geography on a physiological basis. These works directed attention to the nature of plant habitats and prepared the ground for the elaboration of new and quantitative methods of studying vegetation. Many such methods were developed in America by F. E. Clements, whose *Research Methods in Ecology* (1905) for a long time remained the only book of its kind.

The first account of existing types of natural vegetation in the British Isles was published in 1911 under the title *Types of British Vegetation*. The British Ecological Society was founded in 1911, and began to issue the *Journal of Ecology*, the first and still the best journal of its kind. A guide for beginners in ecological work was provided in 1923 by the publication of Tansley's *Practical Plant Ecology*, and three years later, under the editorship of Tansley and Chipp, appeared *Aims and Methods in the Study of Vegetation*, a general guide to ecological methods, for use within the British Empire. The aim of this work, a result of the Imperial Botanical Conference of 1924, may be gathered from the following quotation from the preface (p. v.):

"It is hardly possible to conceive a property owner or stores manager carrying on the management of a large estate or general store and yet being unaware of the stock at his disposal, the extent of his supplies, or their nature. And yet this is, in the main, the position of the British Empire, its Tropical Colonies and Protectorates in general, and even, to a certain extent, its great Dominions, so far as one of its greatest assets—natural vegetation—is concerned. No inventory of the vegetational assets of the Empire has been attempted, nor, so far as is known, is any officially contemplated."

Thus even from the purely materialistic point of view the great and growing importance attached by botanists to the study of plant ecology is more than justified.

CHAPTER II

STRUCTURAL BOTANY

What is a plant? At one end of the scale are such colossal growths as the giant redwood-trees of California, whose stems may soar upwards well over a hundred yards, and whose age may reach some thirty centuries. At the other end come the Bacteria, minute yet potent organisms, able to reproduce their kind by division once or more an hour, and so small that of some types over 100,000 individuals placed closely side by side would scarcely stretch across a halfpenny.

Between such extremes is an almost infinite variety of form and size. Microscopic spheres and cylinders, sedentary or endowed with means of locomotion, isolated or united as colonies or filaments (simple or branching), characterise the Bacteria and many of the Algæ and Fungi. Other Algæ consist of thin plates of tissue, as may be seen in the common green sea lettuce and the red dulce of tidal shores, where also occur the more complex, strap-shaped, branching bodies of species of sea wrack (*Fucus*), and the long, stout stems and pliant brown blades of the kelp *Laminaria*. Some of the giant kelps of northern seas, such as *Nereocystis,* may reach ten yards in length, while off the west coast of South America *Macrocystis,* the largest of them all, may double the length of a redwood-tree.

Unique forms are encountered among the Fungi. Moulds and mildews which thrive in moist atmospheres consist of a web, or *mycelium,* of fine, branching threads applied closely to the surface on which they grow, and bearing aloft on slender stalks myriads of reproductive cells, so light that a puff of wind disperses them in clouds. Others, like the mushrooms, toadstools, and the great bracket forms found on dead or dying trees, are built up of closely intertwined, cohering filaments, rather resembling the structure of a cable.

Then there are the scaly green growths of the Liverworts, so abundant in moist ravines and on wet banks, and the dry, multicoloured scabs of the Lichens, which lend gay coats to tree trunks, walls, and rocks. Mosses, with their slender stems and delicate green leaves, more closely resemble the plants of our fields and gardens, though they lack true roots and flowers.

Among the Ferns much greater complexity of form and structure obtains, ranging from that of the minute "filmy" ferns of wet rocks, through the common garden and woodland types with shuttlecock habit, and the bracken with its long, vigorous, underground stems, to the great tree ferns of New Zealand and the climbing species of tropical jungles.

Among the Cycads, of warmer climates, forms like those of the tree ferns are found—*e.g.*, the "sago palm" (*Cycas revoluta*), whose leathery fronds are often used for decorative purposes on Palm Sunday. The structure and growth of the stems and roots of these plants are not much unlike those of our common trees. Conifers, like pine, larch, and cedar, are closely similar in organisation to our native forest trees, yet, like Cycads, they lack true flowers, having complicated "cones" in their stead.

Among the Flowering Plants the greatest diversity of forms exists. Yet through them all runs a common plan, infinitely varied in its application. The stem bears leaves at definite points called *nodes*, and from the *axils* of the leaves—*i.e.*, the angles between leaf stalks and stem, arise buds, the beginnings of shoots and flowers. A bud is like a telescoped shoot and develops into one by the elongation of its *internodes*, the portions of its stem between the nodes. At the ends of shoots flowers may be borne, either singly or grouped in *inflorescences*. These are the essential features of the organisation of the higher plants, except for the root system, which varies greatly. There may be a main or *tap root*, swollen in the carrot and beet; or a number of more or less equal roots may replace the first one, thus giving a *fibrous* root system; sometimes several of the roots become *tuberous*, as in the dahlia. In the ivy and many tropical Aroids, roots arise directly from the stem, when they are described as *adventitious*.

Many striking modifications of plant organs are known, among the most interesting of which are the hollow leaves, or rather leaf tendrils forming the brightly coloured death-traps of the insectivorous pitcher plants (*Nepenthes*); the stout, stilt-like, adventitious roots of the screw pines and the banyan tree; the *pneumatophores* or breathing roots of mangoes, which grow upwards above the waters of tropical swamps and estuaries; and the massive, columnar, leafless stems of the giant *Cereus* of the Mexican deserts, stems holding in extreme cases up to twenty-five tons of water.

Plants differ greatly also in their internal structure, being soft and juicy, as in most of the simpler types like Algæ, Fungi, and Liverworts, or differentiated into softer and harder portions, as in most other groups. By cutting thin sections with a razor, and examining them with a microscope, the actual details of construction can be made out. In general such a transverse section of a very young stem appears rather like a honeycomb, which resemblance led Robert Hooke (1665) to use the term *cell* for the cavities, and " interstitia " for the partitions separating them. The cells of the stem section are not all alike, but differ considerably in size and shape and in the thickness of their walls. Moreover, groups of similar cells occur, constituting *tissues*, of which there are several kinds, each having one or more principal functions, such as conduction, strengthening, or storage.

Since all types of plants show this cellular construction, and some are unicellular, the cell may be regarded as the structural and physiological unit of the plant. A simple plant cell consists of a thin-walled box made of *cellulose*, containing the living matter, or *protoplasm*, which is the physical basis of life. The cell wall is a dead secretion elaborated by the living matter which it surrounds and protects. Many of the reproductive cells of plants do not secrete a wall. Hence the term " cell " is often used now to denote a completely organised unit of protoplasm, or *protoplast*, though in practice it is frequently convenient to retain a loose use of the term to indicate the cell wall irrespective of its living contents.

Protoplasm, still one of the world's greatest mysteries, is a viscous, transparent, colourless substance rather like the albumen of an egg. Under the microscope it shows but little differentiation, though careful observation reveals the presence of minute granules, as well as a much larger and more refringent mass known as the *nucleus*. This structure is, so to speak, the brain of the cell, for it seems to exert some form of control over its activities, and is essential for its normal functioning, although many cells lose their living contents at maturity. Although the nucleus appears to have been observed previously, it was Robert Brown (1773-1858) who first called attention to it as a regular feature of the cell (1831). Later, von Mohl (1805-1872) insisted that the cell contents were of living matter, which he termed *protoplasma*. The universal presence of cells in living organisms was emphasised by Schleiden (1804-1881) and Schwann (1810-1882), who in 1838 founded their *Cell Theory*. These investigations, together with those of Nägeli (1817-1891), finally established the cellular nature of living organisms, and afforded a rational explanation of their orderly growth and development.

In young cells, like those at the tips of roots and shoots, the protoplasm usually fills the whole cavity. Gradually the volume of the growing cell begins to exceed that of the protoplasm, in which small *sap vacuoles* appear—*i.e.*, cavities filled with a watery solution of organic and inorganic substances like sugars and mineral salts. These vacuoles increase and coalesce, ultimately forming one large one, thus leaving the protoplasm as a lining pressed closely against the wall. The diameter of the vegetable nucleus varies from 1/25,000 inch to 1/40 inch, though commonly between 1/5,000 inch and 1/1,000 inch. In the very young cell it nearly fills the cavity, but in older cells it is relatively small. Within it may be seen one or more large granules, more highly refringent, and known as *nucleoli.*

The nucleus is far from homogeneous in structure, and by appropriate methods of examination many details have been made out. In order to do this the tissue has to be killed and " fixed," or coagulated, during which process the semi-fluid protoplasm sets to a firmer consistency, allowing it to be sectioned without displacing its inclusions. After fixing with alcohol, chromo-acetic acid, formalin or other fixative, the tissue is dehydrated with absolute alcohol, and is then infiltrated with melted paraffin wax. When thoroughly impregnated the material is placed with wax in a mould and a small block is cast. The cooled block is then attached to a microtome, a precision instrument working somewhat on the plan of a bacon slicer, but capable of cutting rashers 1/10,000 inch or less in thickness. The thin sections of wax and embedded material adhere by their edges to form a ribbon, short lengths of which are fixed on glass slides and stained after the removal of the wax. Thus a nucleus may be cut into several slices, and its structure examined with lenses magnifying more than a thousand diameters. It is possible to differentiate the various structures present in the nucleus by means of stains, some of which are retained by one kind and not by others. It has been established that all living cells have much in common.

The vegetable nucleus appears to be bounded by a definite though delicate membrane of undetermined nature. Within this membrane, in addition to one or more nucleoli, there is a firmer reticulum of material usually termed *linin,* in which is present, either as minute granules or distributed more uniformly, another substance termed *chromatin* because it stains strongly with certain dyes which do not affect the linin. Filling up the interstices of the réticulum is nuclear sap or *karyolymph,* so that the whole nucleus somewhat resembles a loosely tangled ball of wool, saturated in water and enclosed in a tightly fitting bag.

The rest of the protoplasm, outside the nucleus, is called *cytoplasm,* and in it there may be sundry granular, or rod-like structures which of recent years have been distinguished as *chondriosomes* or *mitochondria,* and *Golgi bodies,* about which much remains to be discovered. In addition, small deposits of various organic reserves usually occur. In the cells of green tissues there are also numerous protoplasmic globules associated with the green pigment *chlorophyll.* Such structures are called *plastids,* and in this case are termed *chloroplasts.* A general name for plastids associated with pigments is *chromatophore.* Cells pass through three stages in their development —viz., formation, growth, and differentiation.

The bulk of the softer tissue of a young herbaceous plant is composed of cells of the general type described above, and known as *parenchymatous,* if all the sides of the cell are about equal in length, or *prosenchymatous* if much elongated. Running longitudinally through the stem are a number of tougher strands arranged more or less in a circle as seen in a transverse section. Such strands can be pulled out easily from a stalk of celery, and are known as *vascular bundles.* They are composed of fine, elongated cells, many of which form long tubes and serve to conduct water and substances in solution. Two regions of a vascular bundle can be distinguished in a cross section, the larger one towards the centre of the stem being composed, on the whole, of wider and much thicker walled cells than the more peripheral one. This inner zone is the wood, or *xylem,* and is separated from the outer one, or *phloem,* by a layer of thin-walled cells called the *cambium.* Wood, especially older wood, varies greatly in composition, though characteristic for each kind of plant, on which account microscopic identification and comparison of timbers is possible. Some cells of the wood are parenchymatous in nature, remain living, and to some extent serve to store and distribute organic reserves like starch, sugar, fats, and proteins. Other wood cells have very thick walls, so thick sometimes that the cell cavity, or *lumen,* is almost obliterated. Such cells usually die when mature, and have long, tapering ends which overlap their neighbours, and by thus dovetailing in amongst one another the cells of such a tissue confer strength upon the wood. Similarly constructed *fibres* also run in the older phloem, and in some woody relatives of the mallow, lime and mulberry constitute the "bast" used for tying purposes in the garden.

The most conspicuous elements of the wood are the *vessels,* thick-walled, dead cells, which have become connected to form long, continuous tubes, owing to the disintegration of the end walls of vertical rows of cells. Such vessels may be several yards in length, and as much as 1/25 inch in diameter, and are easily visible to the naked eye in canes, vine, and oak.

Another type of wood cell, which, like the vessels, is largely concerned in water conduction, is the *tracheid,* a single elongated, fairly thick-walled, dead cell, with oblique pointed ends and numerous pits. The walls of fibres, vessels, and tracheids are not composed solely of cellulose, but undergo chemical changes during development, and become hard and *lignified.* The presence of *lignin* in the wall can be detected by many reagents, and if allowed to remain in wood pulp used for paper making lignin will cause the paper to turn yellow in sunlight. For better quality paper made from wood pulp the lignin is extracted.

In addition to fibres phloem also contains parenchymatous cells, usually of slighter construction than those of the wood, but of similar functions. The most important element of the phloem is the *sieve-tube,* which, like the vessel, is formed from vertical rows of cells, whose end walls become perforated like sieves, and so throw their contents into communication. Sieve-tubes have thin walls, remain alive, and in Flowering Plants are associated with more slender elements called *companion-cells,* which have conspicuously large nuclei. While the functions of the companion-cells are still obscure, though they may be secretory, it is widely believed that sieve-tubes provide important channels for the conduction of sugars and other organic substances elaborated in the leaves, though this function has also been assigned to the xylem elements, a proposition rather difficult to accept in the case of certain water plants which develop abundant phloem but very little xylem.

The vascular bundles of an ordinary herbaceous stem are separated by radial bands of tissue known as *medullary rays,* since they extend from the pith or *medulla* in the centre of the stem to a zone outside the phloem known as the *pericycle,* in which fibres often occur. The pericycle itself is bounded by a compact cylinder, one cell in thickness, called the *endodermis,* between which and the outer skin, or *epidermis,* is the *cortex,* parenchymatous and largely concerned with support and storage. Where their corners are thickened, cortical cells form *collenchyma,* a strengthening, yet elastic tissue.

Between most living cells, except in the phloem, narrow *intercellular spaces* occur, through which air and gases can circulate among the tissues.

Many minor modifications of the above arrangements are to be found in vegetable stems, some of which are very complex. The above description applies only to *Dicotyledons,* or plants with (usually) two seed-leaves, or *cotyledons.* In *Monocotyledons,* with but one seed-leaf, like cereals, lilies and palms, the vascular bundles are far more numerous, and are scattered more or less regularly all over the stem, as seen in cross section. Moreover, many of them have their bundles enclosed in sheaths of thick-walled cells, or *sclerenchyma,* which when freed from the adjoining parenchyma, provide bristles for brushes and brooms.

In roots the xylem and phloem form separate strands arranged alternately along the circumference of a circle, and are situated nearer to the centre, where they are best disposed to resist the pulling strains to which roots are subjected.

The anatomy of the Flowering Plants on the whole is more complicated than that of other groups, and this is to some extent correlated with the conditions of life upon land to which large, fixed plants are exposed.

CHAPTER III

GROWTH

One of the most striking properties of protoplasm is its ability to create new protoplasm, in short, to grow. Research has established the fact that protoplasm is a *colloidal* substance—*i.e.*, one which exists in a state of extremely fine division—the individual particles being beyond the limits of direct microscopic vision. Many such natural substances are known—*e.g.*, proteins, gums, glue, and gelatine—and by appropriate means many solid substances can be brought into the colloidal condition. Similarly liquids can be made to produce *emulsions,* which are colloidal, as may be demonstrated by shaking oil and water vigorously together, when the oil will break up into minute droplets, which under certain conditions will remain suspended in the water indefinitely.

Certain kinds of colloidal substances, notably glue and gelatine, are hard and brittle when dry, but in contact with water they absorb it vigorously, and gradually pass through the condition of a jelly into that of a *sol,* as a fluid colloidal mixture is called. On withdrawing the water a continuous reversal of these changes ensues, and the substance once again becomes brittle. The jelly stage is known as a *gel,* and protoplasm is considered to have to a large extent the structure of a gel—viz., an extremely fine meshwork of particles, between which continuous, though intricate, watery pathways exist.

Living protoplasm may be likened, more or less satisfactorily, to a rich vegetable soup, strained and thickened with gelatine, so that on cooling it barely sets. There is, however, good reason to believe that a high degree of organisation exists in protoplasm, as a result of which the multitudinous activities of the cell are carried out in a co-ordinated and harmonious manner.

One result of the fine subdivision characterising the colloidal condition is an enormous development of the surface of the dispersed substance in contact with the other component of the system. Since, in addition to being distributed throughout the plant as thin layers covering the walls of innumerable microscopic cells, protoplasm is colloidal, its substance makes remarkably intimate and extensive contact with the fluids of the cells. Inasmuch as all surfaces are the seats of *surface energy,* and energy is convertible from one form to another, this arrangement facilitates the amazingly rapid operations carried out by living matter.

In the dry state, however, protoplasm is inactive, and may sometimes remain dormant for many years. Thus it is recorded that seeds of the sacred lotus germinated after they had been stored for over 160 years. The first requisite for growth is water, without which seeds will not germinate. Another requisite is oxygen, and yet another is a suitable temperature.

The rate of chemical change is approximately doubled for each rise of 10° C. (van't Hoff). Within limits growth follows a similar law with rising temperature, but after the attainment of a certain temperature, depending on many circumstances, further rise decreases the rate of growth, which finally ceases. Thus growth, like many other biological phenomena, shows a very characteristic relation to temperature, in which three conspicuous points occur—viz., a *minimum,* below which growth is impossible, an *optimum,* at which it is most vigorous, and a *maximum,* beyond which it ceases. Such a relation suggests that at any rate up to a certain point growth is conditioned by the rates of chemical reactions.

Oxygen is absorbed during growth, and appears to enter into combinations with the protoplasm and certain of the cell contents, particularly fats and carbohydrates. One result of the changes which take place is the evolution of carbon dioxide. It must not be supposed, however, that a simple combination of oxygen and carbon in the plant is all that happens, for it is now known that many highly complicated chemical changes, involving much molecular rearrangement, occur during this process of *respiration.*

Another result of respiration is the liberation of energy, partly in the form of heat, which cannot be detected unless steps are taken to enclose the tissues and prevent loss of heat by radiation. This energy is released during the oxidation and decomposition of substances stored in the tissues—*e.g.*, starch, sugars, and fats, so commonly found in seeds. The process may be compared with the oxidation of coal in a furnace, or of petrol in the cylinders of a motor-car, in which considerable heat and energy are given out and can be made to do work. In the plant, however, " low temperature combustion " seems to occur, and under normal conditions the plant, unlike the higher animals, remains approximately at the temperature of its surroundings. Energy is liberated, however, and is utilised in promoting other reactions in the growing tissues. Growth implies movement, and therefore the transporting of materials, for which energy is required.

Hence, the value to the young plant of a supply of respirable substances, which provide both building materials and the energy with which to use them. As a rule, without oxygen respiration ceases, and growth with it, though *anærobic respiration—i.e.,* respiration in the absence of free oxygen—occurs among the lower plants, and to a limited extent among the higher ones, where, however, it seldom liberates sufficient energy to promote growth.

The first stage in the germination of a seed, an excellent example of growth, is the absorption of water, which is imbibed strongly by the cell wall and the dry cell contents. Further entry of water results from a process known as *osmosis,* which may be described as the passage of water through the protoplasmic membrane under the attraction of various crystallisable cell contents, such as sugar and salts. A familiar example of the osmotic entry of water into vegetable tissue is seen when raisins are soaked in water.

Protoplasm appears to let water pass through it very much more readily than many salts and other soluble substances, for which reason it is often described as a *semi-permeable membrane.* It must, however, be emphasised that the behaviour of living protoplasm in this respect depends upon many factors, and presents problems quite outside the scope of this book.

As water accumulates it sets up a hydrostatic pressure, which tends to stretch the cell. When the walls have reached the limits of their elasticity, or when their tension balances the force with which the water is being drawn into the cell, no more water can enter, unless some can first escape, say, from one side into an adjacent cell. In this condition the cell is said to be fully *turgid,* and its protoplasm is pressed against the wall, so that the cell, as a whole, becomes more or less rigid, like an inflated football.

The entry of water into the cell starts its elaborate chemical machinery. *Enzymes,* or "ferments" as they used to be called, begin to act on some of the complex chemical substances stored in the seed, and break them down to substances of simpler constitution. Thus *starch* is converted by the enzyme *amylase* (*diastase*) to the sugar *maltose,* which in its turn is seized upon by another enzyme called *maltase* and is broken down to the still simpler sugar *dextrose* (*glucose*). *Zymase* converts *dextrose* into *alcohol* and *carbon dioxide.* Similarly the *proteins* of the seed are broken down, or digested, by other enzymes, and are transformed into comparatively simple substances. *Fats* and *oils* are acted upon by *lipases,* which produce from them *glycerine* and *fatty acids* of various kinds.

Many other changes are brought about by enzymes, each as a rule being responsible for one particular reaction alone, so that life has sometimes been described as "just one enzyme reaction after another." The whole series of chemical transformations involved in the growth and nutrition of plants is known as *metabolism,* the up-grade, or constructive changes being differentiated as *anabolism,* and the down-grade or destructive ones as *katabolism.* Under certain conditions enzymes also act synthetically, constructing complex compounds from simpler ones.

A single cell—*e.g.,* yeast—may contain more than a dozen different enzymes, though it is only about 1/3,000 inch in length. In all, about thirty different enzymes have been obtained from yeasts. As all of these enzymes, and the substances on which they act, are bodies of fairly elaborate chemical structure, and the cell as a whole works harmoniously, some idea may be gathered of the marvellous nature of living matter, as well as of the difficulties which beset those who seek to probe its mysteries.

Starch, proteins, and fats are insoluble in the cell sap, and cannot pass from one cell to another, for movement of a substance within the plant depends upon its ability to diffuse in solution through the protoplasm and cell walls. The products of enzyme action mentioned above are all soluble and diffusible, and so are able to move away from their original places of storage to regions where they are utilised for respiratory or constructive processes.

Eventually the reserves of the seed are all used up, and further development becomes impossible unless more materials are forthcoming. In ordinary circumstances the plant obtains its supplies from two sources, the air and the soil. The plant gets all its mineral constituents from the soil, in which they occur in very dilute solution. Many chemical elements may appear in an analysis of vegetable matter, but experiments have shown that there are some seven soil substances which are essential for growth. This has been demonstrated by the method of *water culture,* which consists in placing young plants with their roots in vessels containing solutions of known composition, differing from one another only in the omission of a single element. In the absence of *nitrogen, sulphur, potassium, phosphorus, calcium, magnesium,* or *iron,* unsatisfactory growth or death results, whereas in a solution containing all seven elements in due proportions vigorous growth results, provided the solution is kept aerated and is renewed as the substances are withdrawn from it. It may be noted that in the absence of iron the plant suffers from *chlorosis,* or inability to develop its green colour, a sort of vegetable anæmia curable by the timely addition of traces of iron salts to its diet.

In the lower plants the various chemical substances enter through the general surface in contact with them, but the higher plants possess a specialised absorptive system in the *root hairs,* delicate, tubular outgrowths arising from the outer skin, or *piliferous layer* of the roots, shortly behind their tips. The root itself elongates rapidly immediately behind the tip, owing to the growth in length of the cells which are formed at the tip itself. A little further from the end growth in length ceases, as the cells then begin to undergo differentiation. It is just here that the root hairs are to be found forming minute bristle-like projections, continually developing from cells nearer the apex, living for a short time and then collapsing, so that the root hair region advances with the root tip. The walls of the root hairs are exceedingly thin, and become firmly cemented to particles of soil, so helping to fix the young seedling in the ground.

The plant thus synthesises new plant substance from the raw materials of the air and soil. This method of nutrition affords the fundamental difference between plants and animals, for the latter ingest their food, and with few exceptions have some kind of alimentary canal system. In both cases, of course, the food substances finally enter the cells by diffusion in soluble form, and are then assimilated by the protoplasm.

After its reserves are consumed, or even before then, the plant becomes self-supporting, and steadily increases in size. Obviously something more than the mere stretching of cells occurs during growth. Actually new cells are produced by the division of pre-existing ones, a doctrine firmly established by the researches of Nägeli (1844). Not only does every cell arise from a pre-existing cell, but every nucleus comes from a pre-existing nucleus, as was first definitely proven in plants by Strasburger (1879).

Nuclear division precedes cell division, and may occur in two different ways. Direct division, or *amitosis*, restricted to the simplest plants and senescent cells of a few higher ones, is brought about by the constriction of the nucleus near its middle, the two portions subsequently separating. Indirect division, *mitosis*, or *karyokinesis*, is the more usual mode of nuclear division both in animals and plants. The process, which may be completed in an hour or so in some cases, is extremely complicated, and here it is quite impracticable to give more than a generalised outline account. It may be noted, however, that numerous researches upon animals and plants have established the fundamental similarity of nuclear division in the two kingdoms.

The cells of a growing region, or *meristem,* like a root tip, are especially favourable for the examination of nuclear division. Such a cell, just before dividing, and seen in a suitably stained preparation, has the appearance already described. As division begins the chromatin becomes more conspicuous and stains more deeply, and the reticulum gradually gives place to a series of tangled threads, which show a more or less double nature, and constitute the *spireme.* These threads separate out, become shorter and thicker, and form *chromosomes,* of which the nucleus of each kind of animal and plant has a constant and characteristic number. Thus the nucleus in each cell of a tobacco leaf has forty-eight* chromosomes, which, curiously enough, is identical with the number in each nucleus of the smoker!

The nuclear membrane disappears, and a spindle-shaped figure having the appearance of a number of fine fibres stretched across the cell from opposite poles gradually develops. The real nature of these spindle *fibres* is uncertain, and they may represent lines of stress in the cytoplasm, rather than any more substantial portions of it. The chromosomes become arranged across the middle of the spindle, and each one splits longitudinally into two equal portions. The halves then separate to opposite ends of the cell, as if pulled by fibres, and gradually lose their compact form, return to the reticulate condition, become enclosed by a new membrane, and form daughter nuclei, between which a new cell wall is secreted. The exact nature of the forces directing the division and the subsequent movements of the chromosomes has not yet been ascertained.

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* An Old World species of monkey, *Rhesus maccacus,* also has the same number of chromosomes.

Since each chromosome undergoes an equational division it follows that each daughter cell receives an equal share of its parental chromosome equipment. It is now generally accepted that chromosomes not only retain their individuality throughout their existence, even during the reticulum stage, but that they are the bearers of factors, whatever the nature of these may be, responsible for the appearance of hereditary characteristics, such as colour, form, size, etc. From this will be recognised the profound significance of the mode of nuclear division just described, especially when it is added that there is good reason to believe, with the American investigator Morgan, that each of the factors to which reference has been made, resides in a definite portion of a particular chromosome. Thus each of the chromosomes houses a whole series of factors differing from one another, and arranged within the chromosome like the beads of a necklace.

By cell division tissues arise. A single cell may give rise to a simple row, forming a filament, or division may take place by walls inclined at various angles, thus producing branching filaments, plates, or masses of cells. By the subsequent growth and differentiation of the cells, all kinds of plants are systematically built up, the architecture and *ontogeny,* or order of development, being characteristic for each.

Very complex structures are formed in the case of trees. From acorn to oak-tree is a far cry, but an outline of the development may be given. The acorn has two cotyledons filled with reserves enabling the seedling to get a start in life. The root on emerging strikes downwards under the influence of gravity, and the *plumule,* or young stem, grows in the opposite direction. This response to gravity is called *geotropism,* and results in the root securing a hold in the earth, and in the stem displaying its leaves to advantage in the light. Much discussion has arisen as to the nature and causes of geotropic curvatures, and of the *heliotropic* curvatures brought about by unilateral light, which at present are but imperfectly understood.

By continued division of the cells of the apical meristems of root and shoot new tissues are added, and these undergo differentiation and give rise to the structural features which have been described. Further growth, however, is made by the cells of the cambium, which at an early stage comes to form a cylinder, owing to division of cells across the medullary rays to form new cambium cells. By the regular division of the cambium cells, and the differentiation of their products, new xylem elements are added on the inside and new phloem elements on the outside. Thus the original xylem and phloem of the primary bundles become separated by the growth of concentric cylinders of secondary xylem and phloem between them. New medullary rays are formed by some of the cambium cells, and in time appear as radial rows of cells extending across the cambium into the regions on either side of it. The diameter of the stem increases, so that the outer tissues become split and are replaced by layers of *cork*, formed by the activity of a cork cambium, or *phellogen*, which arises towards the periphery of the stem. Each year new zones of tissue are added, the increments being marked by conspicuous *annual rings*, owing to the juxtaposition of large cells formed in the spring, and smaller cells formed in the previous autumn. From this feature the age of a tree may be determined. Many museums exhibit portions of the trunks of redwood or other great trees with dates and names of historical interest attached at the appropriate annual rings showing in the section.

The cork, or *periderm*, itself becomes stretched and fissured as the stem increases in girth. Cork is waterproof, gasproof, and elastic, and affords considerable protection to the stem. Numerous radially running channels develop in the cork, and are known as *lenticels*. These structures are formed by the phellogen, and are composed of loose tissue which permits the circulation of air to the interior of the stem. Lenticels can be seen well in ordinary bottle corks, their course being traced as lines of brown powdery cells.

The oak, like other massive plants, develops much fibrous tissue, and its stem and root form many branches. The root also undergoes secondary thickening in a similar manner, though at first the cambium arises outside the primary xylem and inside the phloem strands.

CHAPTER IV

LEAVES AND THEIR WORK

In essentials a leaf is a sheet of delicate green tissue extended by a system of girders which contain conduits for water and organic materials. Throughout all their wide range of form leaves show certain fundamental features of construction. These can best be examined by means of thin sections cut across the leaf and viewed through a microscope. The upper and lower surfaces of typical leaves like those of oak or beech are bounded by an *epidermis* of compactly arranged cells devoid of pigment. The outer walls of the epidermal cells contain *cutin,* an elastic, waterproof, and gasproof substance, which forms a definite outer layer, or *cuticle,* and also impregnates the middle portion of the wall, of which only a thin innermost layer consists of unaltered cellulose. The presence of cutin checks water loss and affords some protection against the attacks of fungi and insects.

The epidermis does not form a continuous sheet, but is perforated by innumerable openings called *stomata,* through which gases and water vapour can pass. Each stoma is of microscopic size, the largest known being of the order of 1/1,000 inch in length and half that in breadth. On the other hand stomata are extraordinarily numerous, a well-grown sunflower leaf having a total of more than a dozen millions.

A stoma usually consists of a pair of *guard cells* the adjacent walls of which have become separated along part of their length, so that a narrow, slit-like opening is left between them. Many varieties of stomata are known, but most have walls which are of unequal thickness and extensibility. If conditions cause the guard cells to become turgid they change in shape, and the pore between them opens, while if the cells subsequently lose their turgor the pore closes again. To some extent the stomata thus regulate the rate of gaseous exchange between the interior of the leaf and the atmosphere.

Beneath the upper epidermis are one or more layers of slender, thin-walled, cylindrical cells, arranged with their long axes roughly perpendicular to the surface of the leaf. These are termed *palisade cells.* Great numbers of chloroplasts line the walls of the palisade cells, and between the latter run narrow *intercellular spaces* in which air can circulate in contact with the moist cell walls. Sometimes several palisade cells converge on to a cell called a *collecting cell,* but frequently they are connected directly with the cells of the *bundle sheath,* a compact layer bounding the vascular bundles which branch freely inside the leaf.

The larger vascular bundles are accompanied by tissue almost devoid of pigment, and often having in transverse section a girder-like form, particularly well seen in the thick midribs of many leaves. The cells of these girders, when turgid, expand and stretch the epidermis, so that the whole leaf tends to become rigid like an inflated cycle-tyre does. On loss of water the cells become soft and flaccid, like a deflated tyre, and the leaf then wilts. If not left too long in this condition, the leaf will recover its turgor on addition of water, which becomes osmotically drawn into the cells. Turgidity is essential for the proper functioning of the leaf.

The rest of the leaf is composed of a very loosely arranged tissue of delicate cells, less rich in chlorophyll than the palisade, and known as the *spongy mesophyll.* Many variations in detail are to be found in leaf structure, but the above description applies to the majority of our common plants of cultivation.

Leaves carry out two important processes: *photosynthesis,* or the manufacture of organic substances under the influence of light, and *transpiration,* or the giving-off of water vapour.

Several factors are concerned in photosynthesis—viz., *light* of appropriate wave-length, chiefly the red-orange rays; *chlorophyll,* the universal green pigment of plants; *carbon dioxide* and *water,* together with a suitable *temperature* and the presence of *living protoplasm.* Photosynthesis has received much attention by plant physiologists, notably by Dr. F. F. Blackman, of Cambridge.

Under the combined action of the factors enumerated above synthesis of organic compounds proceeds at an astonishing rate. Among the first easily demonstrable products of photosynthesis are sugars and starch; the formation of starch has been recorded as occurring within five minutes of illumination in *Spirogyra,* one of the common green pond scums. There has been, and still is, much diversity of opinion as to the nature and sequence of the chemical changes leading to the synthesis of these carbohydrates in the leaf. On the one hand, it has been thought that the simpler hexose sugars, like dextrose and levulose, appear at an early stage, possibly as the result of the rapid polymerisation or condensation of molecules of *formaldehyde,* formed by the photochemical reduction of carbon dioxide in the presence of chlorophyll and water, and that the more complex sugars—*e.g.,* cane sugar—then arise from the hexoses, after which starch is deposited inside the chloroplasts, when a certain critical concentration of sugar has been exceeded. On the other hand, numerous experimental results have been interpreted as indicating that the hexose sugars arise by the simplification of cane sugar, which is then regarded as the first sugar of photosynthesis.

How far ultra-violet radiation present in sunlight is concerned in these syntheses is still uncertain, but the laboratory production of simple carbohydrates from carbon dioxide and water has been described, and tentative schemes have been formulated for the simultaneous elaboration of these and other compounds in the plant from raw materials obtainable from the soil.

The term *carbon assimilation,* often used as synonymous with photosynthesis, in practice is applied more particularly to the synthesis of carbohydrates by chlorophyll in light. It is highly probable that proteins and other compounds are also elaborated in the leaf, the nitrogen being brought there from the soil as nitrate, which is produced from decaying organic matter by various nitrifying bacteria.

More certainty prevails with regard to the external factors affecting photosynthesis, such as light intensity, temperature, and concentration of carbon dioxide, thanks mainly to the work of Blackman and his collaborators. In 1905 Blackman formulated his important principle of *optima and limiting factors,* the essence of which is that when a process is conditioned by the interaction of several factors, its rate is limited by that of the " slowest " factor, just as the strength of a chain depends upon that of its weakest link. Thus, it is found that given an adequate temperature and a sufficiency of carbon dioxide, the rate of photosynthesis depends upon the light intensity. If the light intensity is increased the rate of photosynthesis increases with it, and continues to do so until temperature, carbon dioxide supply, or some other factor sets a limit again. On the removal of the limitation imposed by the new limiting factor, once more the rate of photosynthesis increases, and so on until a final limit is reached conditioned by the structure of the plant and the protoplasm within it. This principle has many applications in plant physiology.

The source of the carbon dioxide used in photosynthesis is the atmosphere. The fact that the atmosphere normally contains only 3 parts in 10,000 of this gas, led the earlier investigators to think that the carbon forming so large a proportion of the plant could not possibly be obtained from this source. However, the careful investigations of Blackman and others have shown beyond all doubt that not only does atmospheric carbon dioxide provide all the carbon of the plant, but that this gas enters the leaves through the stomata, whose relative frequency on the upper and lower faces of the leaf determines the relative rates at which gaseous exchange proceeds through the two surfaces.

During photosynthesis carbon dioxide is absorbed and decomposed and oxygen is liberated, precisely the opposite to what occurs during respiration. Just what happens between the absorption of carbon dioxide and the evolution of oxygen is by no means clear, though usually the volume of carbon dioxide absorbed is equal to the volume of oxygen given out, and either can be used as an index of the rate of photosynthesis. This liberation of oxygen during photosynthesis is easily seen on exposing leaves of submerged aquatic plants to sunlight, when bubbles will arise from the leaves as long as carbon dioxide continues to reach the chloroplasts by diffusion in the water. This explains one use of plants in aquaria. The amount of carbon dioxide respired by a green organ during daylight is much less than the amount which it can decompose during photosynthesis. Hence, normally no evolution of carbon dioxide from green organs occurs until photosynthesis ceases at dusk. On the other hand, all active plant tissues without chlorophyll evolve carbon dioxide at all times.

The actual rate at which an active sunflower leaf decomposes carbon dioxide during a favourable summer day is round about 1/50 gram per square decimetre per hour, which, at a rough approximation, means anything between one and two grams per square foot during the day, and would involve the diffusion into each square foot of the leaf surface of an amount of carbon dioxide normally contained in between 60 and 120 cubic feet of air.

Such a high rate of gaseous exchange formerly seemed incredible, but mathematical investigations into the laws of diffusion of gases through finely perforated partitions, together with convincing demonstrations of actual rates of diffusion through such partitions and into leaves, have removed all doubts about the efficacy of the stomata as paths of gaseous exchange.

Since, in the absence of limiting factors, leaves can carry out photosynthesis more actively in concentrations of carbon dioxide above that of the atmosphere, attempts have been made, notably at Cheshunt, to obtain greater crop yields by increasing the concentration of carbon dioxide inside glasshouses. Some encouraging results have attended the work, which is not yet far beyond the experimental stage.

Our knowledge of the chemistry of chlorophyll has been gained chiefly from the researches of Willstätter and his collaborators, who have shown that two varieties of chlorophyll, distinguished as *a* and *b*, are present in green tissues. The empiric formulæ of these two chlorophylls are $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$ respectively. In addition, two other assimilatory pigments occur in foliage leaves—viz., *carotin* ($C_{40}H_{56}$), which is orange in colour, and *xanthophyll* ($C_{40}H_{56}O_2$), which is yellow. The exact relationships of these four pigments to one another in the various stages of photosynthetic activity is still largely a matter of conjecture, as are also the rôles of various other pigments, such as the yellowish *flavones,* and the red, violet, and blue *anthocyanins,* which are widely distributed in the cell sap of leaves and flowers. It is, however, fairly certain that enzyme activity enters into both photosynthesis and respiration, and that in the latter process pigments play an important part in connection with the transference of oxygen from one compound to another.

The products of photosynthesis pass from the palisade cells, where they are most actively formed, into the collecting cells, and thence towards the vascular bundles. The exact paths followed by the assimilates from the leaves are still uncertain, as also is the mechanism of their *translocation*. Many facts, both structural and physiological, point to the phloem, and in particular the sieve-tubes, as affording the main-line transport system for both proteins and carbohydrates throughout the plant body. Critical demonstration of the downward translocation of organic substances in the outer layers of the xylem, as suggested by Professor Dixon, of Dublin, is not yet to hand, and at present the balance of opinion favours the phloem as the tissue in which longitudinal transference of these substances chiefly goes on.

All diffusible substances can, however, move in any direction in the plant, and thus can supply deficiencies wherever they arise. The medullary rays are important as affording tissues for the radial distribution of organic substances, which they also store in considerable quantities, especially during the winter.

Many tissues, in addition to medullary rays, accumulate reserves, and some plant organs have as a special function the storage of such substances. Thus, fleshy underground stems are often rich in starch and proteins, as in the iris and potato; or they may contain *inulin,* a carbohydrate rather simpler in composition than starch, as in the Jerusalem artichoke. Inulin is also stored in the tuberous roots of the dahlia, while other fleshy roots, like parsnip, beet, and carrot store considerable quantities of sugars. Many fruits and seeds contain reserves and provide important supplies of starchy food, as in cereals and bananas, or are the sources of valuable oils, as in the olive, and many palms and other plants.

Many plants with fibres are exploited for the manufacture of tying materials and for paper, and recently the production of power alcohol from plant substances by special fermentation and distillation methods has reached a commercially profitable stage. One enterprising cane sugar factory in the tropics has even been able to meet all its working expenses from the sale of power alcohol obtained from the cane residues from the crushing-mills. There is even some hope now that the prickly pear, which has rapidly overrun more than thirty million acres in Australia and elsewhere, may soon cease to be regarded as merely a troublesome pest, and will be made to provide considerable supplies of spirit for industrial purposes.

There is an enormous field of work for a very long time in "economic" botany, or the proper exploitation of plants. Fortunately the funds of the Empire Marketing Board are being utilised to some extent in aiding work of this kind. It need hardly be said that money utilised for such purposes can scarcely fail to prove a very profitable investment, even if the returns are not immediately forthcoming.

Under natural conditions the reserves in the plant are reconverted into soluble substances on the resumption of active growth. From such sources come the flowers that bloom in the spring before leaves have been formed on the plant. Although the green leaf is one of the chief feeding organs of the Flowering Plant, there are some which derive their organic food in other ways. Thus *parasites* feed upon other living plants from which they absorb nutriment by means of various kinds of suctorial organs, as in the dodder (*Cuscuta*), and the tropical *Rafflesia,* which produces the world's largest flower—about a yard across. Both of these are devoid of chlorophyll, *Cuscuta* having only minute flowers and no leaves, and *Rafflesia* having a vegetative structure resembling a mycelium in its host plant.

Hemi-parasites like mistletoe, eyebright (*Euphrasia*), lousewort (*Pedicularis*), etc., develop green leaves, but withdraw other supplies from the roots of various plants.

Saprophytes produce no chlorophyll, and usually thrive where humus exists. Native saprophytic Flowering Plants include the bird's-nest and coral-root orchids, the broomrape (*Orobanche*) and toothwort (*Lathræa*).

Insectivorous plants like sundew (*Drosera*), bladderwort (*Utricularia*), the pitcher plants, and Venus' fly trap (*Dionæa*) obtain some organic nitrogen from the bodies of the insects they trap, while certain plants, notably of the pea family, absorb the remains of bacteria which live in nodules on their roots and can assimilate nitrogen from the air.

Lastly there are the Fungi which have no chlorophyll, and are either parasitic or saprophytic, the former types causing enormous damage to other plants.

The nutrition of the normal green plant is termed *autotrophic*, and that of the other types mentioned above *heterotrophic*.

The water which is lost by transpiration is replaced by absorption from the soil, and this involves a *transpiration current* in the tissues of the stem. It was formerly supposed that the living cells of the wood in some way exerted a pumping action on the water, but later experiments showed that poisonous fluids could be drawn up for many feet in a leafy stem, and that they continued their ascent until they reached and killed the leaves, after which the current ceased. This, with other experimental results, has suggested that leaves are essential for the ascent of sap, which certainly could not be raised to the tops of tall trees solely by atmospheric pressure, or by capillary attraction inside the fine tubular vessels and tracheids known to provide the actual water paths.

Briefly, the generally accepted view of the mechanism of the ascent of sap, as put forward by Dixon, is as follows: From the wet walls of palisade and spongy mesophyll cells of the leaf water vapour passes into the intercellular space system of the leaf, and thence through the stomata into the outer atmosphere. The walls of these cells imbibe water from the contiguous protoplasmic linings to replace that lost by evaporation, and the protoplasm, in its turn, draws upon the reservoirs of cell sap, which thus become more concentrated. When two solutions of unequal concentrations are separated by a semi-permeable membrane, water will continue to pass through the membrane from the weaker to the stronger solution until, if possible, the two solutions attain the same concentration. Hence the sap of the cells from which evaporation is taking place tends to withdraw water from neighbouring cells with which previously they had been in equilibrium. The sap of these other cells thus becomes more concentrated, and in its turn draws water from adjoining cells. In this way chains of absorbing cells are established, ultimately connecting the transpiring cells with the bundle sheaths surrounding the endings of the vascular bundles.

The bundle sheaths absorb water from the fine vessels of which alone the bundle endings consist, and thus set up movements of water within the xylem. Under certain conditions, such as are quite likely to obtain in vessels and tracheids, a column of water, owing to its cohesion, possesses considerable tensile strength, and can be made to transmit a pull almost as if it were a rope. Accordingly, it is supposed that the pull set up by the evaporating leaf cells in the columns of water in the xylem is transmitted throughout the plant, ultimately resulting in withdrawing water from the roots.

The xylem ends in the roots in the region from which the root hairs arise, and from the latter it receives further supplies of water by absorption from the soil and radial transference through the cortex, etc. In early spring water may be forced into the vessels by *root pressure,* the existence of which is demonstrable if a stem is cut through near ground level, when water will exude in considerable quantity for a long time. The mechanism of root pressure has been the subject of much discussion, but it includes the osmotic attraction of soil water by the contents of the root hairs, the transference of this water radically through the cortex and endodermis of the root, in accordance with the water-absorbing capacity of these cells, and the final exudation of liquid into the cavities of the vessels, whose lower ends abut on the relatively impermeable walls of the cells near the root apex.

Root pressure, however, contributes very little to the actual ascent of the sap, except in the early spring before the leaves are developed. It may, however, help to form the drops of water which often exude from definite water pores, or *hydathodes,* which may resemble stomata but are without movable guard cells.

Bleeding, or the copious exudation of liquid from cut stems, as of the vine, is due only partly to root pressure, and is chiefly attributable to the secretory activity of cells near the wound. Remarkably large amounts of liquid may thus be forced out from cut surfaces, perhaps the most striking example being that of the young axis of the great inflorescence of the "century plant" (*Agave americana*), a succulent native of Mexico, which may yield nearly 200 gallons of fermentable juice from which the intoxicating drink "pulque" is made.

The chief value of transpiration to the plant is in its cooling effect, for evaporation of water results in considerable absorption of heat. As long as transpiration continues the temperature of the leaf remains below the point at which danger would result to the protoplasm.

The rate of transpiration is affected by many factors, some of which are purely external, such as those promoting evaporation from any wet surface, and others which are inherent in the structure of the leaf and the changing nature of its cell contents. The guard cells of the stomata tend to open in light and to close in darkness, but the actual closing hours vary enormously both with different individuals and with the same individuals under different conditions. It seems clear that the stomata only control water loss at all closely when they are more than half closed, the purely external factors exerting the chief effect at wider apertures. Moreover, the stomata do not always respond at once to changes in the environment, and rapid and dangerous water loss may occur before the guard cells begin to be effective in checking transpiration.

Closure of the stomata not only checks transpiration, but also hinders photosynthesis, so that protection against undue water loss may involve diminution in food production. Such considerations are not without interest for all who cultivate plants under glass, where proper watering and ventilation demand constant attention.

The actual amount of water which passes through the plant may be termed the *water turnover,* and is of less vital importance to the plant than the *water balance,* or the difference between the amount absorbed and that transpired during the same period. As long as absorption exceeds, or at least equals, transpiration, all is well.

There are many plants which are characteristic of natural situations in which a satisfactory water balance is not easily secured. Such plants usually possess structural features, the net result of which is to reduce transpiration, and they are termed *xerophytes.* Plants not possessing such features are unable to compete with those which have them, so that the latter have the places to themselves.

Other plants flourish where water is constantly abundant, and these are termed *hydrophytes.* They usually have numerous stomata on their sub-aerial organs, a thin cuticle, and well-developed *aerenchyma*—*i.e.*, tissue having very large intercellular spaces which allow free circulation of air to the submerged organs.

The majority of the garden and agricultural plants of temperate regions live in average conditions, and so are known as *mesophytes*. Many perennial mesophytes are *deciduous*—*i.e.*, they shed their leaves in the cold season, and as absorption is then difficult, while evaporation may be considerable, such a great reduction of exposed surface is decidedly advantageous.

The general physiological considerations dealt with in connection with the leaves of the higher plants are largely applicable to the green organs of plants in general, except that submerged organs do not develop stomata, but obtain their supplies of carbon dioxide, as of mineral salts, in solution in the surrounding water.

CHAPTER V

REPRODUCTION

THE ability to reproduce their kind characterises living as opposed to non-living things. Some wonderful instances of the rapid multiplication of particular species of plants are known. Among these may be mentioned the spread of the prickly pear over millions of acres in Australia and elsewhere; the conquest (1920-25) of at least 100,000 acres of New Zealand by the blackberry, and the almost miraculous extension of the cord grass (*Spartina Townsendii*) over the tidal mudlands of the English Channel, many square miles of which have been converted into sea meadows since the discovery of the grass in 1870, at Hythe, near Southampton.

The simplest types of plants, such as the Bacteria, increase in number by a process known as *simple fission*. An individual, on attaining full size, simply becomes constricted about its middle, and later the two parts separate, each to form a new individual capable of repeating the process. Two or three generations may thus arise in an hour, and if all the resulting products continued their activity unchecked a single individual would generate between 200 and 300 millions in a day. It has been calculated that the volume of bacterial substance so produced in a couple of days would probably occupy over 30 cubic miles, and in one day more would equal a mass more than 30,000 times that of the earth. Fortunately many causes combine to prevent the occurence of such an embarrassing state of affairs!

The yeast plant reproduces by a modification of fission known as *budding*. A weak spot develops in the wall of the minute oval cell, a bulge gradually appears and the "bud," or new yeast cell, subsequently separates from the parent. Reproductive cells called *conidia* are formed in a somewhat similar way by many Fungi, especially the Mould Fungi, in which they often form long chains of lightly attached cells, readily dispersed by air currents.

Among the green Algæ many types form motile reproductive cells, or *zoospores,* by the subdivision of a protoplast to give two or more smaller individuals, each equipped with fine, whip-like, protoplasmic *cilia,* or *flagella,* with which they propel themselves through water. In multicellular types usually such subdivision is restricted to certain of the cells, the remainder then having a purely vegetative function, and constituting a body, or *soma*. Unicellular organisms reproducing by such *brood cells,* as they may be termed, are virtually immortal, since nothing but the dead cell wall substance disappears at each division.

Non-motile reproductive cells called *spores,* are formed in many Algæ and Fungi by the rounding up of a protoplast, or of part of the protoplasm of *cœnocytic* (multinucleate) forms. Such spores usually have thick walls and a reserve of food, and undergo a rest before developing into a new plant by the rupture of the wall, and the growth of its contents.

There is, however, another and fundamentally different method of reproduction, involving the fusion of two protoplasts, and known as *syngamy,* or sexual reproduction. This occurs even in the simplest Algæ, where motile *gametes,* as the reproductive cells are called, arise in much the same way as the zoospores do. Gametes differ from asexual zoospores in that they cannot as a rule form a new plant until two of them, derived from different parental protoplasts, come into contact and their substance mingles. From the union of gametes a *zygote* is formed, and this gives rise to a new plant either directly or indirectly after dividing to form several zoospores, each of which can grow into a plant.

In other types the gametes are non-motile, and reach each other by means of connecting tube-like outgrowths of the cell walls, through which one or both gametes pass prior to undergoing *conjugation.* It is possible to trace all stages between reproduction by the fusion of equal gametes, or *isogamy,* and well marked *anisogamy,* or *heterogamy,* in which one gamete is small and active and the other larger and relatively passive. Such differentiation of gametes marks the first stage in the evolution of sex in plants, the smaller gamete being regarded as the male. Many specialised structural features are associated with the development of gametes, which in the multicellular plants are usually borne in special reproductive organs. Thus in the Algæ, the female gamete, the *ovum,* or *egg cell,* may be a non-motile protoplast, provided with ample reserves, and protected during its development by being retained within the wall of the parent cell, which is known as the *oogonium*. The corresponding male gamete, the *antherozoid*, or *spermatozoid*, is usually motile and free-swimming, and is produced in a special cell, the *antheridium*, from which it escapes through an opening in the wall. The immediate product of fusion is then called an *oospore*, and this usually remains dormant for a time after developing a resistant wall.

Among the Liverworts and Mosses (*Bryophyta*) greater complexities prevail. The biciliate antherozoids are coiled and thread-like, and are formed in multicellular antheridia. The ovum is retained in the base, or *venter*, of a slender, flask-shaped, multicellular *archegonium*, in the long neck of which is a narrow canal, through which the antherozoid wends its way, apparently in response to some *chemotactic* influence exerted by cane sugar or other substance.

Much the same sort of differentiation prevails among the Ferns and their close allies (*Pteridophyta*), but striking differences are found between the structures to which the oospores gives rise in these two great *phyla*, or groups of plants. The oospore of a Liverwort grows into a relatively simple stalked structure bearing a capsule inside which form spores, each able to develop into a new Liverwort plant. A similar though usually more complex capsule, or *sporogonium*, is formed from the oospore of a Moss. In each case the sporogonium remains attached to the gamete-forming plant, from which it receives supplies of food. In the more highly developed Moss sporogonia some photosynthesis is carried out. There are, however, no roots to the sporogonia of these plants.

In the Ferns, on the other hand, the oospore develops into an elaborate structure, the plant itself, with complex anatomy, large leaves, and numerous roots. The Fern is an entirely independent organism, immense in comparison with the insignificant *pro-*

thallus, or thin green scab no larger than a thumb nail, on which the antheridia and archegonia were borne. Spores corresponding with those of the Mosses and Liverworts are formed in *sporangia,* grouped in clusters, or *sori,* on the fronds of the Fern, and from them grow prothalli, thus completing the life cycle.

The relative importance of the corresponding stages in the life histories of Bryophyta and Pteridophyta affords a great contrast. Moreover, these two stages, the one sexually and the other asexually produced, follow each other regularly in the life history, and constitute an *alteration of generations,* a subject of much interesting discussion ever since its recognition by Hofmeister about 1850.

Hofmeister also recorded the production of two kinds of spores by the *sporophytes* (spore-bearing generations) of some of the Pteridophyta, which are therefore said to be *heterosporous,* as opposed to *homosporous* types in which only one kind of spore appears. The larger spores (*megaspores*) of heterosporous types give rise to *gametophytes* (gamete-producing generations) bearing only archegonia, and the smaller spores (*microspores*) to gametophytes bearing only antheridia. Such differentiated gametophytes may be described as female and male respectively.

Hofmeister extended his observations to the Conifers, where he was able to show that the microspores of the Pteridophyta are represented by the pollen grains. He further showed that within the seed of the pine and its allies is developed a cell, the *embryo sac,* which corresponds to the megaspore of the Pteridophyta, and which subsequently gives rise to a female gametophyte, or prothallus, bearing simplified archegonia. In Conifers the antheridia also are simplified considerably. Moreover, the gametes are non-motile, and the male one is carried passively to the female by means of a *pollen-tube,* which develops from the pollen grain, or microspore. Such a process is known as *siphonogamy,* and is characteristic of the *Phanerogams,* or Flowering Plants.

Thus it became clear that in microscopic studies of reproduction lay the key to the classification of the *Cryptogams,* or Flowerless Plants. Coming as they did at about the same time as Darwin's *Origin of Species,* Hofmeister's discoveries seemed to provide a rational basis for an evolutionary classification of the whole realm of plants.

Reproduction in the Flowering Plants typically involves three stages—viz., *pollination, transporation* of the male gamete by the pollen tube, and finally *fertilisation* of the ovum. Although a flower may have a protective, leaf-like *calyx* of *sepals,* around an attractive *corolla* of *petals,* the only organs essential for reproduction are the *stamens,* bearing the *anthers* which produce pollen, and the *carpel*(*s*), containing the *ovule*(*s*), or future *seed*(*s*). The tip of the carpel, or "seed leaf" (not to be confused with cotyledon), is often prolonged and enlarged to form the *style,* and this ends in a *stigma* with a surface specialised for the reception of pollen grains.

Pollination consists of the transference of pollen grains from an anther to a stigma. This may be effected by wind (*anemophily*), and insects (*entomophily*), as well as by water, by animals, and by appropriate movements of the floral organs themselves. Numerous interesting correlations between the structure of flowers and their visitors have been described. *Self-pollination* occurs if the stigma receives its pollen from the same flower, and *cross-pollination* if the pollen comes from another plant. Darwin experimentally showed that cross-pollination generally resulted in more, larger, and better seeds than did self-pollination.

Two or three nuclei pass into the pollen tube which carries them with it during its growth down the style to the cavity containing the ovules. An ovule consists of an ovoid central *nucellus* bounded by two *integu-*

ments, and is attached by a short stalk, or *funicle,* to a *placenta* within the carpel. A cell near the surface of the nucellus develops into a large *embryo sac,* the nucleus of which divides to form eight nuclei, one of which is the ovum. Of the remaining seven nuclei two fuse, two form *synergidæ,* or *co-operating cells,* at one end of the embryo sac, and the other three constitute the *antipodal cells* at the opposite end.

The pollen tube passes through the narrow opening, or *micropyle,* where the integuments leave the nucellus exposed, and by the breaking down of the intervening tissue the contents of the pollen tube and embryo sac come into communication. The two male gametes now present in the pollen tube pass between the synergidæ, and one unites with ovum to form the future embryo, and the other joins the double nucleus of the embryo sac, and by further division gives rise to a nutritive tissue called *endosperm.* If subsequently the embryo enlarges at the expense of other tissues and fills the seed, as in peas and beans, the seed is described as *non-endospermous,* or *ex-albuminous,* while if the embryo remains surrounded by endosperm the seed is said to be *endospermous,* or *albuminous,* as in cereals, castor-oil, date, and coconut.

The integuments usually harden to form the seed coat, or *testa,* and the carpel(s) may undergo considerable alterations. The whole result of fertilisation, which in the apple, strawberry, fig, etc., may involve the floral axis as well as the carpels, constitutes the fruit, of which there are many different kinds. Fruits serve to protect and disperse seeds, which thus may have an opportunity to germinate in places where they do not have to compete with similar adult individuals. As fruits often contain valuable food reserves they are of great economic importance.

The essence of sexual reproduction is the fusion of protoplasts of different origin. This involves doubling the chromosome number, since each gamete brings its quota, which retain their individuality. The observed constancy in number of chromosomes is brought about by a special type of nuclear division which occurs (in seed plants) on the formation of pollen grains and embryo sac, and is known as *meiosis*, or *reduction division*. This was first recorded in plants by Strasburger in 1888, and is essentially similar in animals and plants.

The chromosomes within a nucleus often differ in size and shape, and often their descendants can be recognised from generation to generation by such differences. Now meiosis involves, at its beginning, the pairing of homologous chromosomes from each gamete—that is of corresponding male and female chromosomes having in general the same rôle in the nucleus. Whereas throughout the growth of a seed plant each of its cells has retained the double number of chromosomes arising from the fusion in the embryo sac of its parent, a nucleus which is about to form pollen grains or embryo sac(s) thus comes to have *half* the number of *double* chromosomes. After coming into more or less intimate contact the members of each pair of chromosomes separate to opposite ends of the cell quite independently of the other pairs, thus effecting a reduction division, as each daughter cell will only receive half the original number of chromosomes. While each cell will contain a full set of the homologous chromosomes it would only be a mere coincidence if all the original male chromosomes went to one nucleus and all the original female ones went to the other. Usually the daughter nuclei contain chance mixtures of male and female chromosomes. Subsequently the chromosomes of each of the two daughter nuclei split longitudinally, as in ordinary karyokinesis, and thus, in the simplest possible case, arise four pollen grains, two of one type and two of another.

Owing to certain other modes of division, differing in detail only, and to the independent segregation of chromosomes (and half chromosomes) at each division, many different combinations of chromosomes are possible, and have an equal chance of arising, in the resulting pollen grains. Thus two pairs of chromosomes give four possible groupings, and x pairs give 2^x. In the trio previously mentioned as having each twenty-four pairs of chromosomes, viz., man, monkey, and tobacco, the possible number of combinations, apart from certain further complicating factors, is no less than 16,777,216. Actually the resulting four nuclei will differ in quality from one another only to the extent to which their constituent chromosomes differ from their homologues.

As a rule only one cell of the quartet survives to form an embryo sac in the Flowering Plants. Meiosis precedes spore formation in Bryophyta and Pteridophyta, and occurs at various points in the life cycle of other groups of plants. Its significance in relation to heredity will be indicated later.

The actual nature of sex, and the possibility of controlling its development, are topics of great interest and practical importance. Definite structural differences in certain of the chromosomes are known to be associated with difference in sex in many cases. Though previously discovered in animals, this was first described in plants by Allen (1917), for a Liverport called *Sphærocarpos*. Such chromosomes are termed *sex chromosomes*. Santos (1923) first described sex chromosomes in Flowering Plants (*Elodea canadensis*). Many examples are now known, for the varying details of which advanced works should be consulted.*

Although cytological studies have thus revealed some physical basis of sex differentiation, sex certainly is not determined merely by the presence or absence of one or more odd chromosomes. Undoubtedly physiological factors of the whole environment act upon the physico-chemical organisation of the nucleus, and affect sex determination, as is suggested by the reversals of sex which have been obtained experimentally in staminate and carpellate individuals of hemp and other plants, by changes in illumination, nutrition, etc. Although, as yet, sex determination cannot often be controlled satisfactorily, it has been shown recently that some plants—*e.g.*, maize, can be made to respond definitely to prearranged cultural conditions.

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* It may be noted that sex chromosomes occur in the human species, and are strikingly similar to those of certain monkeys.

Many plants can reproduce their kind from small fragments left in the ground. This is termed *vegetative reproduction,* and involves no nuclear fusion. Another example of this mode of reproduction is seen in the striking of cuttings, and yet another in the practice of budding and grafting. Even detached leaves, as of *Begonia* and *Bryophyllum,* will develop new plants from their edges if placed on moist soil, and certain Ferns normally bear numerous small individuals upon their fronds. Bulbs and corms produce axillary branches which can be separated for purposes of multiplication, and tubers like the potato can be cut into fragments each able to give birth to a new plant from an " eye," or bud. Vegetative reproduction is of the greatest value to planters and others, for, unlike seedlings, plants produced by vegetative methods retain the characters of the parent stock unaltered, so that stocks of desirable types can be multiplied.

There is a real need for further investigations into the structural and physiological considerations involved in the actual practice of vegetative methods of multiplying plants, especially in the tropics where such propagation is carried out on a very large scale. In this connection *Nature* (1924, p. 557) states that " British tropical possessions are as yet ill provided with the large and well staffed experimental plantations on which alone the experimental work can be carried out that is necessary before vegetative propagation can be resorted to upon a large scale with a staple crop. Unless provision is made for the experimental work, and for the demonstration of the new methods to the staffs of the commercial plantations, a few decades may see British tropical products ousted from the markets by the more trustworthy produce from tropical areas developed by other nationalities upon more scientific lines."

CHAPTER VI

SYSTEMATIC BOTANY

So many different schemes of classification of plants have been published that for practical reasons one only is set forth here, viz., that of Engler and Gilg, published in the 10th edition (1924) of their *Syllabus der Pflanzenfamilien,* a handy synopsis of the great work of reference, *Die natürlichen Pflanzenfamilien.* All schemes are bound to be more or less subjective, though they aim at exhibiting the probable course of evolution and natural affinities of plants on the supposition that they have all come into existence by descent with modification from pre-existing types, many of which are extinct.

Plants existed in very early geological times, but our knowledge of the fossil record is extremely fragmentary. The work of Darwin and of Hofmeister led to attempts to build up a genealogical tree for the plant kingdom. Undoubtedly such an aim stimulated systematic work greatly, but in the light of more recent knowledge it is at least very doubtful if even three or four such trees could adequately represent the course of plant evolution. Neither is it certain that any such trees should be conceived as springing from the same geological level. The plain truth is that although much is known about ancient and modern plants, the sum total of such knowledge is as yet utterly inadequate to furnish much more than a vague outline of their course of descent.

CLASSIFICATION OF PLANTS

After Engler and Gilg. (1924.) (*Abridged and Annotated.*)

These authors recognise thirteen great groups or Divisions (Phyla), which they differentiate into Subdivisions, Classes and Sub-classes, Orders and Sub-orders, and Families. Each Family contains one or more Genera, and each Genus one or more Species, of which there may be several Varieties.

I. SCHIZOPHYTA.

- Cl. 1. *Schizomycetes.* (Bacteria. Unicellular, chains or groups. Motile or not. Resistant spores.)
- Cl. 2. *Schizophyceæ* (*Cyanophyceæ*). (Blue-green Algæ. Unicellular or filamentous. Common on moist earth.)

II. MYXOMYCETES (*Mycetozoa*). (Slime Fungi. Often brightly coloured. Saprophytic. Form *plasmodia* [naked masses of protoplasm], and spores. Affinities doubtful.)

III. FLAGELLATÆ (7 Orders). (Flagellates. Ciliated aquatics. Unicellular or colonial. Possibly connected with IV-VI and IX. Colourless or variously pigmented. Simple fission.)

IV. DINOFLAGELLATÆ (*Peridinales*). (Marine. Unicellular. Floating (*Plankton.*) Some colonial forms. Probable affinities with V.)

(?). SILICOFLAGELLATÆ. (Unicellular. Marine. Yellowish. Possibly should be included in IV.)

V. BACILLARIOPHYTA. (Diatoms. Unicellular or colonial. Yellow-green. Sculptured siliceous walls. Largely plankton. Conjugation and spore formation.)

VI. CONJUGATÆ. (Desmids and some filamentous green Algæ. Aquatic. Unicellular types often form chains. Conjugation.)

VII. Chlorophyceæ. Green Algæ. Mainly aquatic. Varied form and reproduction. (*Cf*. Ch. V.)
- Cl. 1. *Protococcales*. (Unicellular or colonial. Mostly motile.)
- Cl. 2. *Ulotrichales* (*Confervales*). (Simple or branched filaments, or plates, or tubes. Attached by "holdfasts.")
- Cl. 3. *Siphonocladales*. (Unicellular or filamentous, often much branched. Attached.)
- Cl. 4. *Siphonales*. (Unicellular, but filamentous, often much branched. Attached.)

VIII. Charophyta. (Stoneworts. Submerged aquatics with whorled branching. Ciliated spermatozoids. Complex products of fertilisation. Green. Affinities very doubtful.)

IX. Phæophyceæ (7 Orders). (Brown Seaweeds. Great diversity of form and structure—filaments [simple and multicellular], plates, branching and strap-like, or with holdfasts, "stems" and "leaves." The larger kelps have complex tissues, including sieve-tubes. Zoospores and gametes, ciliated. Includes the Oarweed [*Laminaria*], and Gulf-weed [*Sargassum*] of the Sargasso Sea, *Macrocystis*, etc.)

X. Rhodophyceæ. (Red Seaweeds. Filaments [simple or much branched], plates, etc. Attached. Sexual reproduction by non-ciliated *spermatia* from *spermogonia*, and female nuclei in *carpogonia* with tube-like trichogynes. Complex products of fusion, including *carpospores*. Asexual plants forming *tetraspores* occur. Some types show regular alternation of sexual and asexual forms.)
- Cl. 1. *Bangiales*. (Filamentous or plate-like.)
- Cl. 2. *Florideæ* (5 Orders). (More complex form and reproduction.)

XI. EUMYCETES. (Fungi. Non-green, parasitic or saprophytic. Unicellular, or with *mycelium* of branching filamentous *hyphæ,* or large body of interwoven hyphæ. Sexual reproduction by ciliated male gametes in a few forms, but more generally by nuclear fusions which may or may not involve specialised organs. Asexual reproduction by ciliated zoospores in a few forms, but mostly by spores in sporangia, and conidia or externally produced spores. Responsible for many diseases. Probably *polyphyletic* [many ancestral stocks], some forms suggesting Siphonales and others Florideæ.)

Cl. 1. *Phycomycetes.* (Algal Fungi.)

Or. 1. *Oomycetes.* (Ciliated gametes, or antheridia and oogonia. Attack fish, vines, potatoes, seedlings, etc.)

Or. 2. *Zygomycetes.* (Mycelium much branched. Sporangia, conidia, and other spores. Sexual reproduction by copulation of nuclei in ends of two hyphæ, forming a *zygospore.* Some cause serious diseases to crops.)

Cl. 2. *Ascomycetes.* (Mycelium often complex. Varying degrees of sexual differentiation. *Ascospores* inside *asci,* often enclosed in complex "fruit body." An extensive and varied group.)

Or. 1. *Euascales.* (Includes mildews, some moulds, edible morel and truffle, ergot, yeast, and forms injurious to fruits and timber, *etc.*)

Or. 2. *Laboulbeniales.* (Many are parasitic on insects.)

Cl. 3. *Protomycetes.* (Parasitic, with intercellular mycelia.)

Cl. 4. *Basidiomycetes.* (Mycelium often forming massive bodies. *Basidiospores* borne on *basidia* of several types. Reproduction involves nuclear fusions with little differentiation of organs. Many have two or more stages in their life histories, each of which may be spent on a different "host" plant.)

S.-cl. 1. *Hemibasidii.* (Basidia simple or divided. Various kinds of spores formed.)

Or. 1. *Ustilaginales.* (Bunt and smut of cereals, etc.)

Or. 2. *Uredinales.* (Rust fungi of cereals, of great economic importance. Many other injurious types, with complicated life histories.)

S.-cl. 2. *Eubasidii.* (Basidia often in a layer or *hymenium.* Considerable differentiation shown in form and structure of plant body.)

Or. 1. *Protobasidiomycetes.* (Includes Jews' Ear fungus.)

Or. 2. *Autobasidiomycetes.* (Basidia usually club-shaped. Includes toadstools, mushroom, bracket-fungi, puffballs, earth-stars, stinkhorns, etc. Many forms injurious to timber.)

As an appendix to Classes 2 and 3 are many incompletely known types grouped as *Fungi imperfecti.* These include some which are injurious to fruit and trees, and also *mycorrhiza* (in intimate association with roots of numerous plants, which they assist). Closely related to Classes 2 and 3 are *Lichenes,* compound organisms formed of Algæ and Fungi living in *symbiosis.*

S.-cl. 1. *Ascolichenes.* (Fungus element an Ascomycete.)
  Or. 1. *Pyrenocarpeæ.* (" Fruit body " [fungal] almost closed.)
  Or. 2. *Gymnocarpeæ.* (" Fruit body " more open. Includes " Reindeer Moss," "Iceland Moss," etc.)
S.-cl. 2. *Basidiolichenes.* (Fungus element a Basidiomycete.)

NOTE.—I-XI = *Thallophyta* (body of relatively low organisation).

XII. EMBRYOPHYTA ASIPHONOGAMA. (*Archegoniatæ.* Archegonia and antheridia. Motile spermatozoids. Water needed for fertilisation.)
  S.-d. 1. BRYOPHYTA. (*Muscineæ.* Gametophyte fairly conspicuous, nourishing relatively simple sporophyte.)
    Cl. 1. *Hepaticæ* (3 Orders). (Liverworts. Aquatic or moist habitats. Gametophyte a simple scaly, strap-shaped or " leafy " *thallus.* Simple sporogonium.)
    Cl. 2. *Musci.* (Mosses. Various habitats. Gametophyte with stem, leaves, and rudimentary conducting tissues. More elaborate sporogonium.)

S.-cl. 1. *Sphagnales.* (Bog Mosses. Very simple sporogonium.)

S.-cl. 2. *Andreæales.* (Small rock forms. Capsule splits.)

S.-cl. 3. *Bryales* (Numerous Orders). (The majority. Capsule with assimilatory tissue; shedding spores through *peristome teeth* after loss of covering lid.)

S.-d. 2. PTERIDOPHYTA. (Vascular Cryptogams. Ferns and allies. Gametophyte inconspicuous. Sporophyte very complex, rooted and independent. Tree forms among living Ferns and various extinct groups.)

Cl. 1. *Filicales.* (Ferns. Large leaves [*megaphyllous*]. Many Palæozoic forms.)

Or. 1. *Marattiales.* (Tropical. Sporangia united.)

Or. 2. *Ophioglossales.* (Adder's Tongue, etc. Differentiated *sporophylls* [spore-bearing leaves]).

Or. 3. *Filicales leptosporangiatæ.* (The majority.)

S.-o. 1. *Eufilicineæ.* (Land forms. Numerous Families.)

S.-o. 2. *Hydropteridineæ.* (Water Ferns. Heterosporous.)

Cl. 2. *Articulatæ.* (Leaves small [*microphyllous*] and in *whorls* [several at one level]. Living representatives relatively small.)

S.-cl. 1. *Sphenophyllales.* (Fossil. Devonian and Carboniferous. Complex spore-bearing "cones.")

S.-cl. 2. *Cheirostrobales.* (Fossil. Carboniferous. Most complex cryptogamic "cones" known.)

S.-cl. 3. *Pseudoborniales.* (Fossil. Devonian. [?] Heterosporous.)

S.-cl. 4. *Equisetales.*

Or. 1. *Euequisetales.* (Horsetails. Some Palæozoic.)

Or. 2. *Calamariales.* (Fossil. Mainly Carboniferous. Many trees. Some heterosporous.)

Cl. 3. *Lycopodiales.* (Microphyllous. Living forms small.)

Or. 1. *Lycopodiales eligulatæ.* (Club Mosses. Homosporous.)

Or. 2. *Lycopodiales ligulatæ.* (Heterosporous.)

S.-o. 1. *Selaginellineæ.* (Little Club Mosses.)

S.-o. 2. *Lepidophytineæ.* (Fossil. Palæozoic. Large. Many with fairly complex "seeds.")

Cl. 4. *Psilotales.* (Tropical. Sporangia united. Small group.)

Cl. 5. *Isoetales.* (Quillworts. Small aquatics. Heterosporous.)

XIII. EMBRYOPHYTA SIPHONOGAMA. (*Spermatophyta.* Phanerogams. Seed Plants. Fertilisation by means of a pollen tube. Gametes motile or not. Embryo developed within seed, usually while latter remains attached to parent plant.)

S.-d. 1. GYMNOSPERMÆ. (Gymnosperms. Seeds not enclosed in carpels. Endosperm [prothallus] before fertilisation.)

Cl. 1. *Cycadofilicales.* (Pteridospermæ. Seed-Ferns. Fossil. Palæozoic.

Complex seeds. Habit of Ferns. Anatomy complex.)

Cl. 2. *Cycadales*. (Cycads. Chiefly tropical. Habit of Ferns. Some tree forms. Motile spermatozoids. Fructifications mainly cone-like.)

Cl. 3. *Bennettitales*. ("Fossil Cycads." Habit of Cycads. Complex "flowers" and "fruits." Mesozoic.)

Cl. 4. *Ginkgoales*. (Maidenhair Trees. Motile spermatozoids. Fossil. Mesozoic. *Ginkgo biloba* is only living representative, probably preserved by Buddhists in temple gardens.)

Cl. 5. *Coniferæ*. (Trees. Compact woody cones. No motile spermatozoids. Includes larch, pine, cedar, yew, "monkey puzzle," fir, etc. An extensive group of great economic value.)

Cl. 6. *Cordaitales*. (Fossil. Palæozoic. Trees of Conifer-like habit. Catkin-like fructifications.)

Cl. 7. *Gnetales*. (Mainly tropical. No motile spermatozoids. Habit more like Flowering Plants.)

S.-d. 2. ANGIOSPERMÆ. (Flowering Plants. Seeds in carpels. Endosperm formed after fertilisation.)

Cl. 1. *Monocotyledoneæ* (11 Orders, numerous Families). (Palms, lilies, cereals, etc. Single cotyledon, scattered bundles, parallel-veined leaves, cambium rare, parts of flowers often in whorls of three.)

Cl. 2. *Dicotyledoneæ*. (Two cotyledons, bundles in rings, cambium present, net-veined leaves, flowers various.)
    S.-cl. 1. *Archichlamydeæ* (30 Orders). (Apetalæ and Polypetalæ. Petals absent or not united.)
    S.-cl. 2. *Metachlamydeæ* (11 Orders. (*Sympetalæ*. Petals united.)

Such then is the plant kingdom, a vast assemblage of varied forms affording a wonderful display of the versatility of protoplasm in reacting to its environment. How far such reactions have been inevitable, and how far "purposeful," or "adaptive," has been a subject of discussion. Little is known of the qualitative and quantitative effects of many environmental factors upon many of the activities of protoplasm. Further physiological studies in plant anatomy, such as have been initiated by Professor Priestley, of Leeds, are needed before it can be known just why a plant comes to possess the particular structure it has.

Neither is there any adequate knowledge of the precise conditions of life which prevailed throughout the aeons which followed the appearance of the first plant. Unfortunately little is known about the beginnings of plant life, though it is generally considered probable that the first plants were marine. There have been a number of speculations upon the origin of land plants, one of the most intriguing of which is that of Dr. Church, of Oxford, published in 1919 under the somewhat formidable title *Thalassiophyta and the Subaerial Transmigration*. Put very briefly, this hypothesis assumes a primæval ocean uniformly covering the whole face of the globe and supporting minute free-swimming plant forms (*plankton*), such as still exist and serve largely as fish food. Subsequently land slowly emerged, and in the shallow seas thus provided attached forms (*benthos*) originated, comparable with our modern familiar seaweeds. From the more highly elaborated benthic types, already having an organisation resembling the roots, stems, and leaves of the modern Flowering Plants, Dr. Church supposes that the first definite land plants appeared as the rocks emerged from the sea, and that they then acquired such features as made possible their later conquest of the earth.

It may be noted that geologists do not generally accept the idea of a primæval uniform ocean, and that no real explanation is given of the actual steps by which the hypothetical ancestral Algæ, highly organised in relation to marine life, became fitted for success on land. Dr. Church, like many others, regards it as probable that the land flora is *polyphyletic* —*i.e.*, derived from many different (algal) stocks.

This transmigration hypothesis takes no account of the evidence from palæobotany, and indeed it is highly improbable that any actual transmigrants, being presumably of a perishable nature, could ever have been preserved as fossils. However, palæobotanists have had a good deal to say about plant evolution, though even such an authority as Dr. D. H. Scott frankly states in his interesting *Extinct Plants and Problems of Evolution* (1924, p. 217), " On a general survey, it is clear that while an evolutionary sequence, in a broad sense, is unmistakable in the records of the past, our knowledge is still far too fragmentary to admit of the construction of anything, like a genealogical tree for the vegetable kingdom.

Plants have been preserved as fossils in many ways. Thus the organ may have become covered with fine silt, which, after attaining rock-like hardness, shows an impression of the surface when cleft open. Sometimes a mould of a stem was made in this way, and after the decay of the plant tissue, the mould became filled and so gave rise to a cast. Such impressions and casts are less instructive than petrifactions, in which the original plant substance became impregnated with calcareous or siliceous matter which formed a stony matrix in which the altered plant tissue remained embedded, rather like a paraffin block prepared for use on a microtome. The palæobotanist, like the cytologist, cuts up his blocks, and with great skill and patience prepares very thin sections, in which it is possible to examine the microscopic features of plants which flourished millions of years ago. Palæobotanists base many of their conclusions relating to plant affinities upon comparative studies of the anatomy of ancient and modern plants. Their problems are complicated by many factors, particularly by the fragmentary and imperfect nature of the fossils themselves. Hence it has happened that isolated roots, stems, and leaves, etc., have been described from different localities under different names, only to be shown to belong to the same plant on the fortunate discovery of all three in organic connection.

The earliest plant remains of value occur in the Devonian rocks,* though plant life existed before these were formed. Although many non-vascular types undoubtedly occurred in this remote epoch it is interesting to note that highly complex vascular plants also flourished, some of them bearing elaborate seed-like fructifications on Fern-like fronds. Such plants are particularly prominent in the Carboniferous deposits, and Oliver and Scott (1903) named them *Pteridosperms* (Seed-Ferns). Subsequently, many fronds previously thought to be those of Ferns were referred to this new group, which obviously was an extensive one and had features in common with those of Ferns and Cycads. It is, however, practically certain that the Pteridosperms were not the direct ancestors of our modern Seed Plants.

During the last few years some interesting discoveries in Early Devonian deposits have been made in the Rhynie Chert beds in Aberdeenshire. These have been described in detail by Kidston and Lang (1917), and show the existence of some very simple vascular plants (*Rhyniaceæ*) having rootless rhizomes, from which arose slender forking stems, with or without scale leaves, and bearing terminal sporangia, rather resembling those of certain Bryophyta. More recently one of these types (*Asteroxylon*) has been described by Drs. Kräusel and Wayland (1923-26) from Middle Devonian deposits in Germany, where complete specimens a yard long were found *in situ*. Although of uncertain affinities, these early palæozoic vascular plants suggest Algæ, Bryophyta, and Pteridophyta in their structure, and raise fresh problems as to the origin of vascular plants, especially as in the same deposits in association with *Asteroxylon,* some plants (*Aneurophyton* and *Cladoxylon*) of very complex vascular anatomy, were also found.

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* For geological periods see Holmes, *The Age of the Earth*, No. 102 in this series.

The Carboniferous deposits show, in addition to Pteridosperms and true Ferns, many gigantic relatives of our modern Horsetails and Club Mosses, as well as great forest trees (*Cordaites,* etc.) of Conifer-like habit and with long leaves and catkin-like reproductive structures.

The Mesozoic rocks as a whole reveal the widespread occurrence of Cycad-like types, including the striking "Fossil Cycads" (*Bennettitales*), whose strange, flower-like reproductive organs and dicotyledonous seeds suggested another possible ancestry of the Flowering Plants.

With very few exceptions indeed, among which may be noted the interesting fruit-like bodies containing seeds, recently described by Dr. Hamshaw Thomas from the Middle Jurassic of the Yorkshire coast (*Caytoniales*), true Flowering Plants do not occur until the Cretaceous deposits are reached, and there they seem to appear suddenly in full strength, leaving their origin an unsolved mystery.

This very brief introduction to palæobotany may be concluded with a quotation from a great authority, Professor Seward, of Cambridge, who, in dealing with his rather revolutionary suggestion that no direct genetic connection exists between Palæozoic and Mesozoic plants, writes (Hooker Lecture, 1922, pp. 237-8) "As new lands emerged from the sea, new lines of evolution may have been inaugurated; the transmigration of marine plants which Dr. Church conceives as a single act may have been recurrent. It may be that we shall never piece together the links in the chain of life, not because the missing parts elude our search, but because the unfolding of terrestrial life in all its phases cannot be compared to a single chain. Continuity in some degree there must have been, but it is conceivable that plant-life viewed as a whole may best be represented by separate and independent lines of evolution, or disconnected chains which were never united, each being initiated by some revolution in the organic world."

Reference may be made here to a very interesting and stimulating hypothesis put forward tentatively in 1907 by Dr. J. C. Willis, and described at length in his *Age and Area* (1922). In this hypothesis it is claimed that the extent of the area occupied by a species within a country indicates the age of that species in that country, subject to certain modifications. Accordingly a species confined to a restricted area is not regarded as a relict, but is considered to be of more recent origin than one which occupies a wider area at the same time in the same country, a view to which not all botanists subscribe. Dr. Willis, however, ably supports his illuminating statements with masses of striking statistics, etc., and has, moreover, promised a future volume on the bearing of the Age and Area hypothesis upon the evolution of plants.

CHAPTER VII

*HEREDITY**

IT is a matter of common observation that the offspring of plants and animals may differ considerably in detail from their parents, though, on the whole, like breeds like.

It is customary to recognise two kinds of variations, *continuous* or *fluctuating*, in which the individuals showing the variation (in colour, weight, size, etc.) form a graded series with most representatives about the mean value, and *discontinuous*, or *mutations*, in which new forms differing markedly from the type suddenly appear, and no intermediate forms occur.

Darwin attached greater importance to fluctuating variations in connection with the origin of new species, which he thought arose chiefly by the slow accumulation of slight differences, and the survival of the fittest forms through the action of a process of natural selection resulting from the struggle for existence. More importance is now attached to mutations in this connection, as providing the material on which natural selection acts by elimination of the unfit. Punnett (*Mendelism*, 1927, p. 186) considers that: ". . . We must regard the mutation as the basis of evolution. . . . For it is the only form of variation of whose heredity we have any certain knowledge." Strong support to this view is also given by Dr. Willis. As to the origin of mutations little is known, though in certain cases they are associated with irregularities in the distribution of chromosomes during gamete formation. In general mutations are inherited in accordance with Mendelian laws, an introductory account of which follows.

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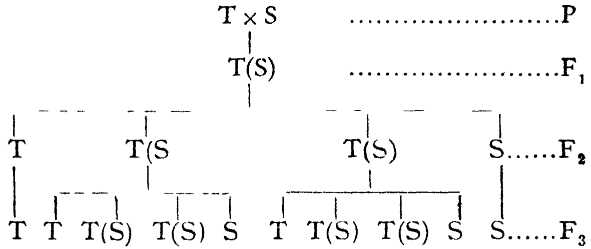
* See also Nos. 109, 110, and 117 in this series.

Mendel used strains of culinary peas in his most important work on hybridisation. He fixed upon definite differentiating characters such as height, colour, and shape of seed, etc., and unlike his predecessors, he used quantitative methods, and also followed up the history of each individual seed and its progeny. The general nature of his methods and results may be gathered from a short description of a typical experiment. Selecting a tall and a short race of peas which had bred true to these characters for several generations after self-pollination, Mendel removed the unopened anthers from a flower of the tall plant and placed upon its stigma pollen from the anthers of a short plant, taking due precautions to prevent the access of any other pollen. He then carefully sowed separately each seed produced from the cross, and found that all the resulting plants were tall. Next he self-pollinated the flowers borne by the plants of this hybrid, or *first filial* generation (F_1), and again planted each resulting seed separately. The *second filial* generation (F_2) showed both tall and short plants, the talls being three times as numerous as the shorts, reckoning the results of a large number of experiments. Continuing the work as before, the F_3 plants from the F_2 shorts all proved to be shorts, and further testing showed that this stock always bred true for this character. The F_2 talls, however, did not all behave alike; one-third of them gave talls only and proved to breed true for this character, but the remainder (=50 per cent. of the F_2 generation) gave talls and shorts in the ratio of 3 : 1. As before, the F_3 shorts bred true, one-third of the talls also bred true, and the remainder threw talls and shorts in the ratio 3 : 1. The results are shown diagrammatically on p. 73.

Mendel thus found that tallness was *dominant* over the *recessive* shortness in the hybrids, but that in the next generation these characters segregated, so that pure talls, hybrid talls, and pure shorts appeared in the ratio 1 : 2 : 1. Mendel realised that the gametes were concerned in this inheritance, and he supposed that one gamete carried a factor conditioning the appearance of the tall character, that the other gamete carried a factor for shortness, but that neither gamete



carried both factors. On fusion the gametes, each pure for one of the factors, gave a zygote containing both factors. Thus, all the cells of the resulting hybrid plant contained both factors, but Mendel further supposed that on gamete formation the factors segregated, so that two sorts of gametes arose in equal numbers, half pure for tallness and the other half pure for shortness. Hence, the hybrid produced two kinds of pollen grains and two kinds of eggs, and since each type of pollen grain had an equal chance of fertilising an egg of the same or of different type, the resulting zygotes would be produced in accordance with the following equation:

$$(T+S) \times (T+S) = TT + 2\,TS + SS$$

TT = homozygous talls.
TS = heterozygous talls.
SS = homozygous shorts.

Such pairs of alternative or differentiating characters were known as ***allelomorphs,*** but many workers prefer to regard the contrasts as due to the presence and absence of the appropriate factors, a question which cannot be discussed here. Bateson introduced the term ***homozygous*** to denote an individual formed from gametes each bearing a particular character, and *heterozygous* for an individual formed from gametes of which one only bore the character concerned. It follows that all the gametes formed by a homozygous plant must contain the factor for which it is homozygous, while only half of the gametes of a heterozygous plant will contain the factor in question. When many factors are concerned the plant can be homozygous for some and heterozygous for others.

Mendel himself investigated about seven pairs of allelomorphs in the pea, and found that coloured flowers were dominant to white, yellow seeds to green, smooth, round seeds to wrinkled ones, etc. Later researches have revealed hundreds of contrasting pairs of characters showing Mendelian inheritance, including such valuable ones as resistance to specific diseases, earlier flowering and ripening of fruit, better milling qualities (cereals), greater yield (various crops), depth of colour, shape of flower, etc. Moreover, Mendel's laws apply to the animal kingdom in respect of numerous important characters, including some borne by mankind. Thus, the work carried out with peas in the monastery garden at Brünn was of the most fundamental and far-reaching importance, for upon the wise and timely application of the methods there elaborated depends much of the future of civilisation.

When Mendel studied the inheritance of more than one pair of characters, he found that each behaved independently of the others, though later work has shown that such is not always the case. Thus, Mendel found that tall pea plants with coloured flowers, when crossed with short ones bearing white flowers, gave seeds yielding plants in which tall forms were three times as numerous as short ones, and coloured flowers three times as numerous as white ones. The actual proportions were found to be 9 tall coloured, 3 tall white, 3 short coloured, and 1 short white.

This chance distribution of characters has been related to the known behaviour of chromosomes during the formation of gametes. At first it was thought that each chromosome bore one or other of the factors, whatever these may prove to be. Later on, however, the discovery of many more factors than there were chromosomes in the nucleus rendered this view untenable. Current opinion inclines towards the ideas developed more especially in America by Morgan and co-workers, who postulate the association of the various factors, or *genes*, with definite portions of the chromosomes, which in the case of a fruit fly named *Drosophila*, they have mapped out into numerous successive lengths each allocated to a particular factor, of which some 400 have been recognised.

The accompanying scheme illustrates the inheritance of two pairs of characters on the assumption that each pair is borne by a different pair of homologous chromosomes—*i.e.*, one character to one chromosome.

(X Y) Gametes. (x y)
Tall. Short.
Coloured. (X x Y y) White.

Zygote.

Separation of homologous chromosomes.
(*First meiotic division.*)
(X Y) (x y) or (X y) (x Y)

Longitudinal division of chromosomes.
(*Second division.*)
(X Y) (X Y) (x y) (x y) or (X y) (X y) (x Y) (x Y)

Hence, four types of pollen grains, and of eggs, which can give rise to sixteen types of zygotes:

1. X Y	2. X Y	3. X Y	4. X Y
X Y	X y	x Y	x y
Tall.	Tall.	Tall.	Tall.
Coloured.	Coloured.	Coloured.	Coloured.

5. X y X Y Tall. Coloured.	6. X y X y Tall. White.	7. X y x Y Tall. Coloured.	8. X y x y Tall. White.
9. x Y X Y Tall. Coloured.	10. x Y X y Tall. Coloured.	11. x Y x Y Short. Coloured.	12. x Y x y Short. Coloured.
13. x y X Y Tall. Coloured.	14. x y X y Tall. White.	15. x y x Y Short. Coloured.	16. x y x y Short. White.

Note that 1, 6, 11, and 16 are the only forms homozygous for both characters. These alone will always breed true, and they include two new forms—viz., 6 and 11. (Dominants = X and Y. Recessives = x and y.)

How far hybridisation in conjunction with Mendelian inheritance and fixation of new types has been responsible for the evolution of plants in nature is still a vexed question. Dr. Lotsy (1916) put forward a theory of evolution by means of hybridisation, and Professor Punnett sees in mutations, and therefore presumably in their subsequent hybridisations, "the basis of evolution." Some experienced workers, however, still seem unwilling to grant a share to such processes in the origination of new species.

The great practical importance of Mendelian methods is that they enable new types to be synthesised by combining character-units selected from desirable sources, for when homozygous such types breed true. Thus Sir Rowland Biffen, of Cambridge, was able to create a valuable new wheat in which were combined good milling properties, heavy cropping and immunity to rust disease. Naturally plant breeders keep a sharp look-out for mutations, and nowadays hybridise on Mendelian lines. Mendelism is indeed the key to plant improvement, and so is one of the most valuable and effective tools available for the exploitation of vegetable resources, a matter of vital importance.

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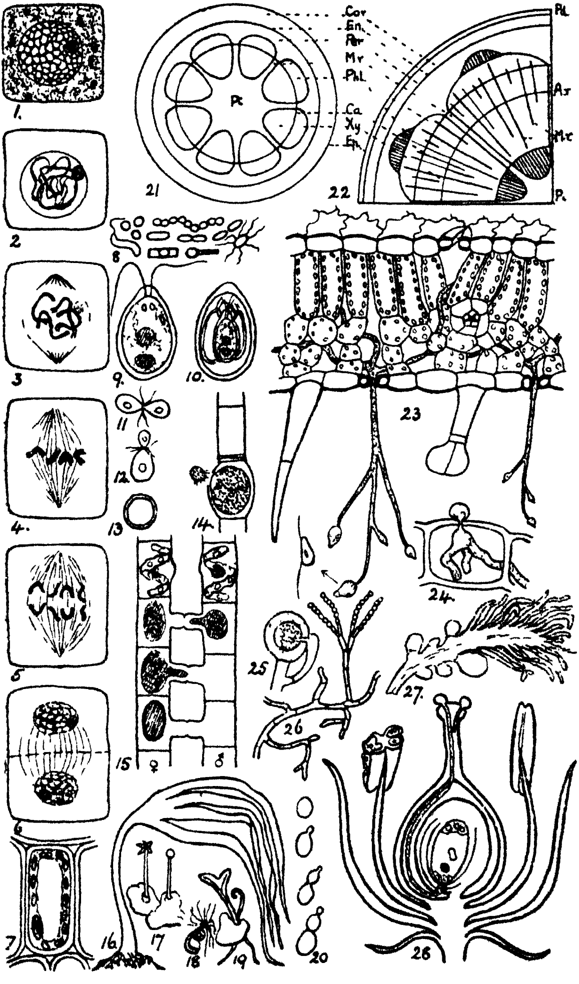
Explanation of Figures.

1-6, Nuclear division; 7, Cell showing protoplasm, nucleus, chloroplasts and intercellular spaces; 8, Bacteria; 9-10, Unicellular Green Alga (*Chlamydomonas*) and zoospore formation; 11, Isogamy; 12, Anisogamy; 13, Zygote; 14, Oogamy in a filamentous Alga (*Oedogonium*); 15, Conjugation in an Alga (*Spirogyra*); 16, A kelp (*Laminaria,* reduced); 17, A Liverwort (*Pellia,* reduced); 18-19, Spermatozoid and (reduced) prothallus and young Fern plant; 20, Budding of Yeast; 21, Transverse section of young dicotyledonous stem; 22, The same after two years' growth; 23, Leaf of potato attacked by *Phytophthora,* conidia and (more magnified) zoospore; 24, A conidium with invading hypha; 25, Sexual reproduction in a Mildew Fungus (*Peronospora*); 26, Mycelium and conidia in a Mould Fungus (*Penicillium*); 27, Megasporophyll of *Cycas* (reduced); 28, Structure of a flower (diagrammatic).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EVOLUTION

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EVOLUTION

CHAPTER I

THE HISTORY OF THE WORD "EVOLUTION"—THE THEORIES OF SPENCER AND LAMARCK

No word is more bandied about in modern conversation than the term "evolution." By the man in the street it is regarded as a kind of modern magic, a contrivance for producing something out of nothing. The evolutionary explanation is that something has mysteriously "arisen" where nothing was before. This procedure is doubtless a little difficult for the ordinary man to understand, but he regards it as all right because it is vouched for by "scientific authority." Scientific authority as expressed in popular books is to a very considerable extent a matter of successful confident bluff, and has a good deal in common with its predecessor, theological authority. It is the purpose of this little book to make clear to the man of ordinary intelligence, but of no special scientific training, what "evolution" really means, and what the evidence is on which the belief is based that evolution has actually taken place and is still going on.

Evolution, then, originally meant nothing more than " unfolding " or " unrolling." It was a descriptive term to denote one of those wonderful processes of Nature which have been going on under the eyes of man ever since he has been man at all and able to observe and reflect. Every spring he has seen the young buds swell and then mysteriously begin to open and disclose the tender leaves, and finally within them all the flower shoot itself. This is what he called " evolution " or unrolling. As scientific reasoning, and indeed all reasoning, ultimately consists in comparing like things together, so in course of time the name " evolution " came to be applied to other processes which seemed to resemble the opening of buds, such as the growth of the constitution of a nation, etc.

In the eighteenth century a fierce controversy broke out between two schools of zoologists, one part of whom termed themselves Evolutionists, whilst the other adopted the name of Epigeneticists. The evolutionists maintained that the development of the animal germ resembled that of the bud; that, for instance, in the embryo of the chicken within the shell all the parts of the future bird were already present, although so closely pressed together that we could not distinguish them; this was denied by the epigeneticists, who said that the embryo chick consisted merely of uniform sheets of tissue on which the form of the organs of the bird was gradually impressed. As means of investigation improved, the epigeneticists were proved to be right and the word " evolution " ceased to be used in this particular sense.

In the beginning of the nineteenth century a French zoologist called Jean Lamarck put forward a theory which the French called " transformism." According to this theory the forms and sizes of animals had gradually changed as the generations succeeded one another when their surroundings (environment) changed. The different surroundings forced the animal to look for its food in a different way and to adopt new devices to escape its enemies; these differing activities involved the use of some organs more than it had previously done and the use of others less. The greatly used organs increased in size whilst those less used decreased in size, and *after the changed habits had persisted for a long time,* the changed size of the organs was inherited—*i.e.,* appeared at birth before the young animal had become active.

This " transformism " was really what the modern biologist understands by the word " evolution," but neither Lamarck nor his contemporaries gave it this name.

In the first half, however, of the nineteenth century, one of the first great English geologists, Charles Lyell, in his famous book, *The Principles of Geology,* described the gradual processes by which the contours of hill and dale are carved upon the face of the earth, by the action of rain and frost and running water, and to these processes he gave the name Evolution.

A little later than Lyell, our English engineer philosopher, Herbert Spencer, came forward with his scheme of "synthetic philosophy," in which he strove—like others before him—to show that everything in the universe could be explained by a few simple principles. He combined the transformism of Lamarck, the geological evolution of Lyell, and the nebular theory of Laplace under the one grand heading of "evolution.' The nebular theory was an hypothesis that the sun and other stars with their attendant planets had resulted from the condensation of rotating celestial clouds or nebulæ. The general impression of the average man that "evolution" is supposed to account for everything is largely derived from the plausible and superficial generalisations of Herbert Spencer. He boldly stated that the activities of animals could be completely accounted for by the motions of the particles out of which their bodies were constituted, and that these motions were due to the same causes and governed by the same laws as those which gave rise to the motions of the atoms and molecules of dead substances. For a hundred years a certain school of physiologists have been endeavouring to bring substantial proof in support of the assertions of Spencer, yet to-day they are further from the attainment of their aims than they seemed to be fifty years ago.

There are two circumstances which render the generalisation of Spencer, to say the least of it, premature; one is the utter failure to construct by artificial chemical synthesis anything which at all resembles living material in its working; and the other is the fundamental similarity of the way in which all living beings work. The same laws which govern the contraction of a man's muscles govern also the movements of the simplest animal, Amœba, which may be described as a drop of naked living jelly; nay, even the plants seem, according to the investigations of Sir Jagadur Bose, to have the same sensitivities as animals, only their lives appear to be of a far more sluggish and duller order than those of animals. If, therefore, there be such a thing as "transformism," this must be deduced from the laws of life, and the motions of the celestial bodies and the chemical changes going on in dead materials afford us no help whatever in proving its existence or in understanding it. Evolution for us is a phenomenon pertaining to living things and to these alone.

CHAPTER II

THE FUNDAMENTAL CHARACTERISTICS OF LIVING THINGS

In another book* of the series to which the present volume belongs, Professor Dakin will give an account of the manner in which the living organism works and of the way in which it is built up, and to this book we must refer those of our readers who wish to have a closer acquaintance with the essential character of life, but a few general principles must be alluded to here.

The active parts of all living beings, plants as well as animals, are drops or small masses of a clear, semi-fluid jelly called "protoplasm." It is in this protoplasm that all the changes take place which result in movement, and in secretion, whether the secretion be bile, milk, saliva, or gastric juice. Protoplasm is the seat of growth—it alone assimilates nourishment and increases in size, and it alone reproduces itself or gives rise to new living beings. By the word "reproduction" is meant the throwing off by the parent of small portions of his or her body termed *germs,* which are alive and are capable of assimilation and growth so that in time they come to resemble the parent. Growth and reproduction are the two great diagnostic features of living beings, and nothing at all like them is found outside the domain of life. The fact that the germ ultimately comes to resemble the parent extremely closely is expressed by the phrase that it "inherits" the form and characters of the parent; but the phrase "inherits" and the cognate phrase "heredity" are misleading metaphors drawn from the human laws of succession in property. The child does not receive its body from its parents; it obtains from the parent only a germ endued with certain specific powers—in virtue of these powers the germ builds up the child's body from food which it receives from the outside world. It is hard to rid the popular mind, and indeed the mind of the crude, unreflecting biologist, of the fallacy that there lurks within the germ a minute copy of the adult body with all its parts complete, which only requires enlargement. This, as we have seen, is the fallacy of the eighteenth century evolutionists, but as we shall show later, the very same fallacy under a different form and name was revived in the nineteenth century by Weismann.

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* *Introduction to Biology.*

The simplest animal is merely a minute drop of this living jelly or protoplasm, and a similar drop constitutes also the body of the most primitive plant, but in the animal the jelly is naked, whereas in the plant it is enclosed in a tight membrane of cellulose —*i.e.*, paper—and this difference runs throughout the whole of the animal and plant kingdoms and separates them from one another. It is true that in the higher animals the living protoplasm is no longer naked, but is divided into small masses called "cells," which are separated from one another by dead membranes, but these membranes are elastic and flexible and allow very considerable movement and change of shape in the contained protoplasm. In plants the individual is likewise divided into cells, but the cellulose membranes surrounding these are far stiffer than the animal membranes, and the movements of plants are slow and difficult to perceive, and are mainly confined to the young and still growing parts, whereas the very idea of the word "animal" connotes something that is obviously active and moves about in search of its food.

A large portion of the bodies of both the higher animals and the higher plants consists of dead material produced by the breakdown of protoplasm, and this material serves as a framework and support for the actively living moving parts; but the germs are small masses of naked living protoplasm; the organism in producing these casts off all the extraneous peculiarities which it has acquired during its growth and reverts to its primitive condition.

Some germs begin to grow as soon as they are shed from the parent, but other germs require to join together in pairs before the combined germ or "zygote" (ζύγον, a yoke) is able to develop. This combination of germ-cells in pairs is the essential element in sex and reproduction by means of zygotes is known as *sexual reproduction*. The object of sex, which is so widespread in both animal and vegetable kingdoms, is a matter on which different opinions are held by various naturalists, but if one takes a broad view of the circumstances under which this phenomenon occurs, it seems to us impossible to come to any other conclusion than that sex is a device to increase constitutional vigour. It seems as if the deficiencies in the powers of one germ-cell were made good by the excellences of another; hence we can understand the well-known evil effects of interbreeding between near relations. We find, in animals and plants where both sexual and non-sexual methods of reproduction are found, that non-sexual methods prevail when food is plentiful and the surroundings favourable, but when hard conditions are impending, such as the onset of drought or of winter, then sexual germs are produced, and the zygote surrounds itself in many cases with a shell of dead material, and is able to lie dormant within it until better times arrive, when it begins to grow.

In the lowest plants and in the simplest animals the two germs which unite with one another are alike, but very early in the scale of development of the higher forms of both animals and plants a division of labour sets in and the sexual germs are divided into two kinds—viz., small ones endowed with the power of movement and larger stationary ones. The two have different tasks to perform; the smaller one has to seek and find the larger one and bring about the union; the larger one has to store in itself a sufficient amount of food to support the young growing organism (zygote) until it can find food for itself. The smaller germ is termed the male germ-cell, the larger the female germ-cell. Amongst animals, both these types of cell soon attain definite forms, which then persist with little change throughout the whole of the higher ranks of the animal kingdom. The male cell takes the form of the *spermatozoon,* a minute, highly concentrated dot of living matter provided with a thin threadlike tail, which by violent lashing about propels the spermatozoon along. The female cell becomes the *ovum* (egg), typically a rounded cell with deposits of food material (yolk) embedded in its protoplasm. There is actually little difference in discernible structure and appearance between the spermatozoon of the humble polyp and of a man; and the egg of a woman is not at all dissimilar to the egg of a sponge, so far as its microscopic appearance is concerned.

The two kinds of germ-cells are usually borne by two different kinds of individuals termed males and females respectively, but in many of the lower animals and in the great majority of the higher plants both kinds of cell are produced by the same individual. In such cases, however, the two kinds of cell are not ripened at the same time, so that union usually takes place between cells belonging to different individuals and so the purpose of sex is served. In plants the crossing is brought about by the visits of insects and by the wind; in the simpler aquatic animals both kinds of cell are discharged into the water and union is left to chance, but in all the land animals and in many of the higher aquatic ones, the male must pursue the female and either inject the spermatozoa into her body, or excite her to discharge her eggs, on which he then deposits spermatozoa. It appears probable that he has also to excite himself before he is able to discharge his own spermatozoa. This quest of the female and the mutual excitement of the sexes constitutes for animals the highest peak of their enjoyment and their principal interest in life; and the ripening germ-cells exert an extraordinary influence on the growth of the body, leading to the formation of what are known as "secondary sexual characters." These take the form in the male, of excrescences such as horns, combs, and beards, and also the enhancement of vocal powers, as well as brilliant colours, and these marks of a ripe male have a powerful influence in exciting and charming the female and making her ready to yield to his advances.

CHAPTER III

THE THEORY OF DARWIN AND THE RESULTS OF PURE LINE INVESTIGATIONS

HAVING gained some idea of the structure of living beings and the manner in which they reproduce themselves, we may now proceed to the further history of the theory of " transformism "—*i.e.*, biological evolution. Jean Lamarck's theory that the living organism reacted to the stimulus of new conditions by new strivings, which in time altered its organs, met with cold response. It was bitterly opposed by Cuvier, the leading French anatomist of the day, and von Baer, one of the founders of the science of embryology, or development, even parodied it as follows: " A fish swimming toward the shore desires to take a walk on land. What more natural than by its efforts it should gradually change its fins into limbs, and its descendants after several generations would doubtless succeed in developing lungs and in getting rid of their gills; their only difficulty would be, in fact, the circumstance that for several generations they would require to exist without breathing at all." It was not until the present year that an Indian naturalist working under my supervision published a paper in which he showed that the transition scoffed at as impossible by von Baer was actually taking place in certain Indian fish, which begin their lives as ordinary fish living in water, but which, as they grow older, begin literally to take walks on land in search of food and learn to breathe air through the soft membrane lining their gill cavities and covered by the gill cover. These cavities, as the air-breathing habit becomes more pronounced, are actually changed into lungs.

But Lamarck had no data to support his theory that the altered activities of animals resulted in alterations in structure. His so-called proofs were really assumptions and begged the question. Thus he considered it obvious that the seal had changed its hands and feet into flippers by becoming accustomed to swimming, and so it came about when in 1859 Charles Darwin published his famous book entitled the *Origin of Species,* that Lamarck's work fell into general neglect, though it is to be remarked that Haeckel, the great protagonist for evolution in Germany, saw no inconsistency between the views of these two naturalists, and dedicated his *History of Creation* to the memory of Jean Lamarck and of Charles Darwin.

The great discovery of Charles Darwin, which will always be associated with his name, is the existence of what he termed " natural selection." He pointed out that every species of animal and plant is continually producing far more germs than can possibly survive, so that the great majority of these must meet with an untimely end. Darwin held that the survivors owed their lives to some little peculiarity which gave them an advantage over their brethren, and that this advantage was handed on to their progeny. These progeny then varied about the new mean as their parents had done about the old one; amongst them only those who had varied from the mean most strongly in the same advantageous direction survived. Thus it would come about that as the generations succeded one another a continuous modification of the organism would take place which would adapt it more closely to its surroundings.

A supplementary hypothesis was put forward by Darwin to account for the peculiarities of males in many species which are known as secondary sexual characters. These he held to be due to two causes, both of which he included under the term " sexual selection " : first, in many species the females chose the male with whom they consented to pair, and the males endeavoured by displaying their peculiarities to attract the females; secondly, in other species the males fought with each other for the possession of the females, and the females willingly paired with the victorious male.

The first kind of struggle led to those males being selected as partners whose peculiarities of colour, shape, or voice were most pleasing to the females; and these males alone would become the fathers of the next generation. As Darwin imagined that variation in the development of these sexual peculiarities was as rife as in the other organs of the body, it followed that the fantasies of successive generations of females would cause the peculiarities of the males to be developed to excess. Thus he accounted for the song of the nightingale, the wonderful ruby throat of the humming-bird, and the tail of the peacock.

The second process led to the exaggeration of the weapons with which the males fought each other. So Darwin explained the spurs of the game-cock, the branching antlers of the stag, and the huge tusks of the wild boar.

A very popular idea is that Darwin has completely explained evolution and that the hypotheses of "natural selection" and "sexual selection" successfully account for all the varied peculiarities of structure and function which we see around us. A little critical consideration will, we think, convince our readers that, so far from this being the case, Darwin's theory is in reality no explanation at all, but one great and striking instance of the common illusion of what one of our best contemporary philosophers calls the "reification" of words—*i.e.*, the conversion of mere general terms into imaginary things.

That every species does in reality produce far more young than can survive is open to no possible kind of doubt. One simple instance of this will suffice. The common thrush lives on an average ten years. It begins to breed at the age of one year, and produces every summer two broods of nestlings, each consisting of four young. In the course of their lives, therefore, a single pair of thrushes bring into the world eighty young, and some of these may be breeding for nine years before the parents die. Since the whole population of thrushes remains about the same from generation to generation, it is obvious that only two of this vast army of children, grandchildren, and great-grandchildren can survive their parents; all the rest must come to an untimely end.

But to put the matter in a nutshell, the fact that James is killed can make no difference to the structure of Tom

The implicit assumption in Darwin's hypothesis is that continuous inheritable variation occurs constantly in all directions. But to assume this is really to beg the whole question. Variation is not a single thing but a collective term for a whole lot of different things. Continuous variation in any direction is evolution, and it is precisely this which has to be proved to exist, and, if possible, to be explained. Natural selection is the pruning-knife which trims the buds of the tree of life, but it does not account for the sprouting of the buds nor for the directions in which they tend to grow.

Darwin relied for the proof of the existence of inheritable variation on the experience of breeders of domestic animals. He spent a considerable number of years in studying the fancy breeds of pigeon. He showed that the peculiarities of these breeds are usually monstrosities of no possible use to the animal, often, indeed, impeding it, such as the enormous crop of the pouter pigeon and the reversed feathers of the owl breed; yet that these monstrosities, when they attract the attention of the breeder, can be continually enhanced by selective breeding; and he suggested that variations like those observed in domestic animals are continually occurring also in wild animals, and thus afford a basis on which natural selection can work.

About the year 1890 a distinguished zoologist, Professor Weldon, put this theory to the test. He collected hundreds of shore crabs from the Plymouth Sound and measured the breadth of their shells. As these crabs were of all ages, he took the length as an indication of the age of the individual; the breadth divided by the length then gave a measure of the peculiar shape of the crab which was independent of its age. These fractions were then collected into groups, the members of each group having approximately the same value. It was then possible to construct a curve. The distance along a horizontal line from the point of origin, or what is called the " abscissa," is made proportional to the particular fractional breadth of the shell, characteristic of each group. At each point so determined a perpendicular (ordinate) is erected proportional to the numbers of individuals in a given group. A line joining the summits of these perpendiculars forms a curve which tells us at the same time how far crabs deviate—*i.e.*, vary—from the typical breadth of shell, and how many of them do so. We learn that the vast majority of crabs have shells which conform to the type, and that crabs which are a little broader or narrower than the type are comparatively common, while extremely broad or extremely narrow ones are very rare.

But the curve tells us something more which is quite unexpected. It is a symmetrical curve—the right and the left halves are almost entirely alike—and this means that the number of crabs whose shells exceed the breadth of the typical shell by a certain amount is equal to the number whose shells are narrower than those of the type by the same amount. Such a curve is known as a *curve of error;* a similar curve is obtained if we measure the distance from the bull's-eye of shots fired at a target. It looks as if in the production of the individuals of a species Nature was aiming at producing a type, but, owing to a variety of accidental circumstances, did not quite achieve it, but that big misses were rare.

But the question now arises, if we were to select two broad-shelled crabs and breed from them, would their progeny vary about the mean represented by their parents, or would they vary about the mean which is typical of the species? This question was answered by another zoologist, Dr. Agar, formerly of Glasgow, now Professor in Melbourne. He did not experiment with crabs, which are exceedingly difficult to rear, but chose instead a small crustacean of the type popularly described as a water-flea, which reaches its adult state in ten days from the time of hatching. This particular water-flea is known as Simocephalus; it carries its eggs in a brood pouch, where they remain until they hatch out as young Crustacea. These eggs develop parthenogenetically—that is, without the intervention of the male—so that there is only one parent to be considered, a circumstance that considerably simplifies the problem.

Agar chose the *length* of the shells of this crustacean as the value to be measured. As the age of the individuals was known, and they were only measured when completely adult, there was no need to express this value as the fraction of anything else. Agar found that the progeny of a long-shelled water-flea were no longer than those of a short-shelled one—that, in fact, the grandchildren varied about the mean of the grandparents and not that of the parents. Under these circumstances no selection, natural or artificial, could bring about any evolution. A similar result was obtained by Jennings, who worked on the slipper animalcule (Paramecium), which belongs to the lowest class of animals (Protozoa), and by Johannsen, who worked on the beans of the scarlet runner. The idea that selection can affect anything arises from the fact that so-called species often consist of races with slightly different typical shapes, and these races may be mingled together in a population. Selection for a special length, breadth, or weight will eliminate from the population all but the members of the race having this character; in this way the average nature of the population will be changed, but once this point has been reached further selection will produce no result whatever.

Agar, Jennings, and Johannsen in each case raised the population with which they experimented from a single individual. This was possible in Agar's case because, as we have already seen, the eggs of Simocephalus develop without the male. In Jennings' case he had to deal with an organism which reproduced simply by dividing into two, and in the scarlet runner the male and female organs are combined in a single flower, so that self-fertilization is possible. Populations sprung from single individuals are known as "pure lines."

These pure-line experiments have dealt a deadly blow at the idea that natural selection is the main agent in causing evolution. The full realization of their implications has not yet reached the ordinary man and not even the ordinary biologist. When it does so we shall hear less about "natural selection" being a completely satisfactory explanation of evolution.

CHAPTER IV

THE MUTATION THEORY OF EVOLUTION

If evolution has really taken place—and for the proof of this we must refer the reader to a later chapter—in some way the hereditary tendencies of the race must have become changed. We have seen that small inheritable variations in all directions do not exist. But Darwin was well aware that sudden and marked divergences from the type turn up in every species, but most frequently amongst domesticated animals and cultivated plants. These " sports," as they used to be called, or " mutations " as it is now fashionable to call them, are often strongly inheritable. Can it be possible that these aberrancies are the raw material of evolution? They occur comparatively rarely; it has been estimated that they are not to be expected in greater numbers than 1 in 100,000 in the case of the banana fly, Drosophila, or in 500 in the evening primrose (*Œnothera lamarckiana*), to name respectively the animal and the plant that have been most experimented with. Yet since only two children of any pair of parents can survive if the population is to remain stationary and many *millions* are often produced by a single pair, a proportion of 1 in 500 or 1 in 100,000 of a favourable variation might be amply sufficient to insure its being handed on to posterity.

De Vries, an eminent Dutch botanist who reared the evening primrose for a dozen years in his botanical gardens, has put forward the " Mutation Theory " of evolution, according to which new species have originated from marked unpredictable sports or *mutations,* occurring from no assignable causes—from causes which, at any rate, are not to be found in the environment. Morgan, the American zoologist who has reared large numbers of the banana fly, has accepted De Vries's theory, and it is probable that it is the most popular theory of the causes of evolution which is prevalent at the present time.

There are, however, insuperable objections to this theory, when the matter is looked at more closely. The rarity of the occurrence of the sports is the first great difficulty, and was clearly seen by Darwin himself, who refused to accept sports as the basis for evolution. It is no valid answer to say that if sports only occur in one out of every 100,000 born, yet only one in 100,000 survives, and so the sports are numerous enough to provide the survivors for the next generation. The effect of natural selection is felt at all stages of a creature's development; what determines the survival at one stage is quite different from what insures survival at another, and a mutation appearing at one period of development, if it were rare, would have very small chance of determining the character of the survivors. To give an example: the white butterfly lays a large number of eggs. Of these a certain proportion perish from the attack of insect parasites. Of the survivors which develop into caterpillars a large number are eaten by birds. Of those that survive these attacks and reach the chrysalis stage, a large number perish from the attacks of insects, which lay their eggs in the bodies of the caterpillars and which develop in the chrysalis. Finally, a number of the adults are devoured by birds. The reader will easily be able to compute the chances of a mutation in the colour of the wing, which occurred only once in 100,000 times, having any effect whatever on the wings of the next generation. But there is another objection to the mutation theory which is more far-reaching and fundamental. It is a postulate of all theories of evolution that at all stages of their racial history organisms must have been efficient working machines, and that the changes which led to evolution must have increased this efficiency. But when we look into the nature of the mutations which have so far been described, we find that, so far from increasing efficiency, they all diminish it. They are, as an American naturalist has expressed it, "failures from the point of view of natural selection." If we look at the list of mutations of the banana fly given by Morgan, it makes melancholy reading. Creatures with shrivelled wings or none, with defective or no eyes, offer a poor prospect of providing under natural conditions survivors for the next generation. But Morgan and his pupils have provided, apparently unconsciously, still another argument against the mutation theory. They have found that all the "mutants," or "sports" of the banana fly, which they rear in glass tubes, differ from the wild banana fly in being less "viable"—that is, in plain language, of less vigorous constitution, dying more easily, and have shorter lives even when carefully tended. The weakness of constitution is proportional to the wideness of the deviation from normal structure exhibited by the mutation. Certainly these mutants do not appear to be promising subjects for natural selection!

Many of the "variations" cited by Darwin in domestic animals are undoubtedly mutations of the same kind as those discovered by Morgan in the banana fly; and we consider it to be the cardinal error of the *Origin of Species* that Darwin regarded these abnormalities as being of the same nature as the differences which separate allied species or races. Here we may see clearly the misleading influence of the general term "variation," under which are grouped together a large number of utterly different things.

What the causes of the mutations are is a question which lies rather outside the scope of this book; but we may say in passing that they seem to be due to an interference with the growth of the germ in the earlier stages of its development. This growth can be analyzed into a series of distinct processes which are to a considerable extent dependent on one another; if one of these is checked it leads to an utterly abnormal result, since the others are unbalanced. The checking of growth is due to abnormal conditions of the environment; if it occurs at a critical period of development, it is handed on to the next generation. These changes occur comparatively frequently in domesticated animals and cultivated plants, because the confined life and insanitary stalls of the animals and heavily manured soils in which the plants are grown constitute extremely injurious conditions for growth.

The whole process can be appropriately termed "germ-weakening." So long as these conditions are maintained, the mutation is propagated practically unchanged. Its increase by selection means the picking out of individuals in which the damage of germ-weakening with the resultant aberrancy of form has been most extreme. But when the conditions are changed to more normal ones the germ-weakening, with its accompanying deviation from the typical structure, tends to pass off. This process is called *reversion*. A very pretty example of this reversion can be seen any day in London. For generations Londoners were fond of keeping tame pigeons. These birds nested in dovecotes and were fed by hand. Darwin has brought convincing arguments that all the varieties of pigeon have been ultimately derived from one species—the wild rock pigeon. This bird is still to be found in the caves on the remoter parts of the Scotch and Irish coasts, but it is nearly extinct. It is a graceful creature with a slender body and long wings. The upper coat of feathers, or "mantle," is dark, slaty-blue; the wings are each crossed near the tips by two black bars. Now a good many of the dovecote pigeons have escaped and lead a wild, self-sustaining life amongst the tall housetops of the London squares, which they doubtless mistake for their ancestral cliffs. Every stage in reversion to the condition of wild rock pigeon can be seen. About two out of every five have regained the full wild plumage; in others which were originally white, the black bars can be seen reappearing as faint blotches of brown; in others which were originally dark all over, the superposed dark colour can be seen to be breaking up into patches, revealing the original slaty-blue colour beneath.

CHAPTER V

THE EVIDENCE THAT EVOLUTION HAS REALLY TAKEN PLACE

If, then, mutations or sports have nothing to do with evolution, if they disappear as soon as natural conditions are restored, the question arises, What right have we to assume that evolution has occurred at all? If the comparison brought forward by Darwin between the success of breeders in increasing the " points " of their " fancy " by selection, and the action of natural selection on plants and animals in wild nature, is an unsound and illusory one, have we any right to assume that the essential nature of wild species has changed since they appeared on the earth? Is the fact that the bones of the flipper of the seal are arranged on the same plan as those of the arm of a man any proof that the one was made out of the other? Might not the Creator, as Sir Richard Owen supposed, have had before His mind certain "archetypes," or general plans of structure, according to which He made living beings, working out each plan in endless variations of detail?

Now, the proofs—it would be better to call them evidences—that evolution has really occurred, that one type of animal has grown into another, are all indirect; they are of the nature of what is called in a court of law circumstantial evidence. Since this growth, or evolution, has been an extremely slow process requiring thousands of years to produce any noticeable effect, we could only obtain direct evidence of it if we had the notes of an angelic recorder who had watched the thing happen and left a record of his observations. We are therefore thrown back on circumstantial proofs of evolution. These proofs can be arranged under three categories—viz., (*a*) the proof from systematic biology, (*b*) the proof from palæontology (*i.e.*, the study of fossils), and (*c*) the proof from embryology (*i.e.*, the study of development). We shall consider these proofs in order, but we shall draw our examples almost entirely from animals because the evidence from plants is much scantier and less satisfactory than that from animals.

(*a*) *Systematic Biology.*—The unit of classification is the species. Like species are grouped into a genus, like genera into a family, like families into an order, like orders into a class, and like classes into a phylum. A phylum includes all the organisms with a recognizable similarity in their general plan of structure, a similarity which on the theory of evolution indicates descent from a common ancestor. Thus the animals like ourselves with segmented backbones belong to the phylum Vertebrata. A species consists of a series of individuals resembling each other closely apart from distinctions depending on age and sex, freely interbreeding with one another and producing fertile offspring, but crossing with difficulty, if at all, with other species, and then producing only sterile hybrids. The question of evolution ultimately resolves itself into the inquiry how the distinct species came into being for the higher grades of classification; genera, families, orders, etc., are obviously only convenient arbitrary collections of species, and their limits vary with the predilections of each naturalist. Thus there are "lumpers" who class a great many species together as a single genus, and there are "splitters" who make out of an old genus a whole array of genera and constitute it into a family. Hence Darwin, in calling his book *The Origin of Species,* went to the root of the matter. Now, as the close study of systematic biology has progressed it is found that every large- and wide-ranging species is divided into local races differing from one another in such slight points as colour of skin, hair or feathers, size, density of fur, or length of limbs. These races interbreed freely where their territories overlap. As these races are studied more closely it is found that their peculiarities are related to the special character of their surroundings. Of this one instance must suffice. There is a beautiful little squirre found in Equatorial Africa called Heliosciurus, which has many local races of different colours of fur. It transpires that the races with lighter coloured fur are found in the depths of the forest, whilst those with darker fur are confined to more open country. The reaction of the skin to sunlight is to produce colouring matter, or "melanin," as we all know from our experience in a summer holiday. Now, the opponents of Darwin who maintained that the Divine Being had specially created every species, nevertheless admitted that the local races were fragments of the same species and *that their differences had been produced by their* different surroundings. But to admit this is, as Darwin showed in the second chapter of *The Origin of Species*, to give away the whole case. For there are many cases where it is impossible to say whether two different forms are two races or two species, and on this point different naturalists take different views. Of course, it may be said that we could test the matter by cross-breeding, since races are fertile with one another, whereas species are not. But in reality this experiment has been made in very few cases, and the limits of species are mostly matters of surmise. No satisfactory explanation of the cause of sterility between species was given by Darwin, although he put forward certain theories to account for it. Since his day, however, evidence has come in which completely substantiates Darwin's theory that sterility is a by-product of increasing difference of constitution. As this point is a fundamental one, we shall give two instances of it. There is in Europe a large frog, the so-called edible frog (*Rana esculenta*), with a greenish skin diversified by black patches. Of this frog at least three races are known to exist—viz., a western in France, Spain, and Portugal, a central in Germany, Belgium, and Holland, and an eastern in the Balkan peninsula and Syria. Each of these races breeds with its neighbour on the border of its territory, and there intermediate types are common. But the eastern race has spread along the north shore of Africa and has reached the southern part of Spain, where it meets the western race, and in this territory the two do not interbreed

It is obvious that if the central race were wiped out, the eastern and western races would be rightly regarded as two distinct species. Again, there is a fairly common moth known as the gipsy moth (*Lymantria dispar*). This moth is spread all over the world from the New England States through Europe to Japan. All the local races will breed with one another, but when two distinct races are crossed the sex of the offspring is influenced by one race more than by the other. This preponderant race is called the strong one. If the father comes from this race the hybrids will consist of males and of females with a good many marks of the male. Such masculinized females are known as " intersexes." In many cases these intersexes are so much altered that they are unable to produce good eggs, and so the cross-breds are unable to propagate themselves, and the two parent races are as mutually sterile as two species, whilst less distant races are still mutually fertile. It follows that there is every gradation between a race and a species, and as races owe their differences to the different effects of their surroundings, so the distinctness of species may be assumed to be due to the long-continued and deeply ingrained influence of different surroundings.

(*b*) In Darwin's day one of the great objections to the theory of evolution was the unsatisfactory evidence from fossils. Fossil species seemed to come in quite suddenly and to disappear as suddenly, so that beds separated from each other by a few hundred feet of rock (which is merely the hardened sand and mud of swamps, lakes, and estuaries) often possessed totally distinct species of the same genus. Darwin tried in various ways to get over this difficulty, none of which was completely satisfactory. Since his time, however, areas have been discovered in the Western States of North America where the deposition of sediment went on apparently without interruption for millions of years. The land on which this silt was deposited consisted of great level meadows, through which a large river flowed. Every spring these meadows were flooded by the spring spate, and many of the animals which grazed on them were drowned. The remains of these animals became embedded in the layer of silt left behind when the flood receded. Thus the layers of silt which ultimately were hardened into rock might be compared to a huge historical book to which one leaf was added every year. In this book we can trace the gradual change in structure in two well-known animals—the camel and the horse. The camel began as a small four-toed animal about the size of a sheep with teeth studded with tubercles like our own back teeth. As time went on the side toes dwindled and eventually entirely disappeared, whilst the upper bones of the two remaining toes coalesced with one another, and the tips of these toes developed the characteristic splay of the foot of the camel, for, as we all know, the camel's weight rests on a broad, horny pad between these toes. At the same time the tubercles on the teeth became broadened into crescents like those on the teeth of the modern camel. The horse also began as a small animal about the same size as the ancestral camel, with four toes on the fore-limb and three on the hind limb, like the modern tapir. The teeth were studded with tubercles. As time went on the fourth toe on the fore-limb (the little finger) diminished and disappeared, and for some time the horse was three-toed like the modern rhinoceros. The side toes gradually diminished, whilst the middle toe (the third finger) became strengthened; but the change went on so slowly that it is almost impossible to say where one stage left off and the other began. "I give you my word," said an eminent palæontologist to me, "these side toes diminish by millimetres at a time." As this process went on the tubercles on the teeth became connected by oblique cross-ridges, so as to give rise to the characteristic W pattern seen on the black teeth of the horse.

The changes in teeth and limbs are correlated with changes both in climate and food. The country at the beginning of the period was soft and marshy. At the close, with the elevation of the land it became gradually changed into dry, hard steppe. The succulent and easily masticated plants of earlier time were replaced by harsh, dry herbage. Hence palæontology emphatically supports the conclusion already drawn from the study of systematic biology that the driving force of evolution was the reaction of the animal to changed environment, and that this reaction produced changes which were handed on to posterity.

Other examples of such evolutionary series are known, as, for instance, that of the sea-urchins in our English chalk; but we have chosen the American examples of the camel and the horse because they are amongst the most familiar animals.

(*c*) *Embryology.*—The study of the development of animals from the egg to the adult condition has yielded many startling instances of similarity between the young stages of certain animals and the adult stages of others. It looks as if certain animals passed through the condition of being other animals before they developed into their own true selves. Every schoolboy is familiar with the life history of the frog, which begins its existence as a fish in many respects a miniature copy of the surviving lung-fish of South Africa and South America, and gradually changes into a land animal. There are thousands of similar instances known, and the impression is unavoidably produced that these young stages are reminiscences of former conditions of the race to which the adult animals belonged.

This impression was crystallized by Haeckel in his great " law of biogenesis." " The embryo," he said, " in its growth to the adult state *recapitulates* the past history of the race."

It must be granted at once that this so-called law is only a daring assumption. There is no obvious a priori reason why the embryo should embody a historical record in its growth. *If it is accepted*, however, it throws a dazzling light, not only on the course, but on the nature of evolution. In our judgment it has been experimentally proved to be true within the last twenty years by a brilliant Austrian naturalist, the late Dr. Kammerer. Dr. Kammerer reared the black and yellow salamander in yellow boxes for four years from the time it emerged from the water till the complete adult condition was attained. The yellow increased in extent till the animals became largely yellow. When two such yellowed specimens were paired and their young confined in black boxes, *they nevertheless became yellower for the first six months of their land life;* then the influence of the black surroundings began to tell; the yellow patches began to be peppered over with minute black dots, and then diminished in size, and the whole animal became dusky. Thus the offspring of the yellowed salamander recapitulated the condition of its parents before yielding to the influences of its immediate surroundings. But a violent personal controversy has sprung up concerning the reliability of Dr. Kammerer's work, and though we ourselves believe it to be perfectly sound, many naturalists refuse to accept it. The question will not be settled till the work is repeated, and as this particular investigation required eleven or twelve years for its accomplishment and an elaborate equipment as well as quite unusual skill in dealing with animals, the chances of its being repeated within measurable time are slight. Nevertheless, so striking are the changes which many animals undergo during their development that almost all naturalists accept the principle of recapitulation, and even those few who profess to reject it unconsciously assume it in their reasonings about the affinities of animals. We are reminded of the phrase which Sir Edwin Arnold puts into the mouth of Brahma: "When me they fly, I am the wings." We might give one or two examples of the kind of life history which has forced the idea of recapitulation on the minds of all who have observed it. The so-called hermit crab thrusts the hinder part of its body (the abdomen) into an empty whelk-shell. In accordance with the shape of the shell, the abdomen differs from the abdomens of all other crabs, lobsters, and shrimps in being curved and in having the appendages developed only on one side. Nevertheless, when the hermit crab is young it has a perfectly straight abdomen like that of a shrimp with appendages equally developed on both sides. If it is prevented from finding a whelk-shell, as it grows the abdomen becomes curved, though not so curved as the abdomen of the crab which is successful in finding a shell.

Again, there exists a class of animals with calcareous plates embedded in their skins and with radial symmetry—that is, with their organs arranged round a centre like the spokes of a wheel round the hub. This group of animals are called Echinodermata (literally, "spiny-skinned"), and include the familiar starfish and sea-urchins. Amongst the less-known members of the class are the beautiful "Feather-Stars." These animals have ten graceful arms radiating from a central disc, in the middle of which is the mouth. On the opposite side of the animal are a number of short, stout-jointed rods called "cirri," which act as grappling irons and anchor the feather-star to the ground on which it rests. The arms are fringed with short branches called "pinnules," and when the feather-star wishes to change its anchorage in the search for a better feeding-ground, it relaxes the hold of its cirri and swims away by undulating movements of its long arms till it finds a suitable spot in which to anchor itself again. Now, when the feather-star is young it is permanently fixed to the ground by a long-jointed stalk springing from the centre of its back, which is strengthened with calcareous plates; but as it grows up the feather-star breaks through the stalk close to its attachment to its body and swims away. In the stratified rocks there are preserved the remains of countless feather-stars, the great majority of which were permanently fixed by stalks like that of the young feather-star. The well-known " mountain limestone " of Derbyshire is in some of its beds largely composed of broken fragments of the arms and stalks of these feather-stars.

Does anyone seriously suggest that in passing through this early stalked phase the modern feather-star does not " recapitulate " the condition of its early ancestors? or that the young of the hermit crab do not resemble the normal ancestor of the race? Some naturalists are willing to admit that there are " reminiscences " of a former condition of the race in some life histories, but maintain that these are of exceptional occurrence and that in the majority of life histories there is no recapitulation. But such a position is very difficult to maintain. Since all life histories have the same starting-point—viz., the fertilized egg, which in its essential structure closely resembles the simplest known animals—it is inherently likely that the general character of development will be the same throughout the animal kingdom. It is true that as time goes on the recapitulatory story embodied in the development undergoes blurring and shortening. It would take us too long to enumerate and discuss all the secondary factors which bring about this result. In general it is the earliest stages of development which have undergone most modification, just as the oldest documents with which the historian has to deal are the most difficult to decipher. Life histories, indeed, may be compared to a series of historical records, which have suffered losses of pages and a good deal of blurring. No one record gives a full or true picture of the past, but by comparing together a large number and laying stress on the points on which they agree, it is possible to sketch in its broad outlines the history of animal life.

Now, the study of development admittedly does not provide such a cogent evidence for evolution as the study of certain "lineage series" of fossils or of the local races of the same species. But once we have become convinced that it really does furnish valid evidence of evolution it carries us much further than the other two sources. The study of local races can only unmask the very latest stages of evolutionary history, and the study of fossils can only give information about those animals which had hard skeletons, and this information is only satisfactory when the skeleton is intimately related to all the organs of the body. The only class of animals with a really satisfactory skeleton is the Vertebrata, the class to which we ourselves belong. From the bones of extinct Vertebrata an enormous amount of information about their structure can be deduced. When we turn to other classes of animals we find in the class Arthropoda (literally, "jointed legs") a vast assemblage, which includes insects, spiders, mites, centipedes, water-fleas, shrimps, lobsters, and crabs, all characterized by having a skeleton which is a kind of exudation or sweat cast off from the skin. The fossil remains of Arthropoda tell us about the external appearance of these animals, but nothing about their internal organs. In other classes of animals, such as the Echinodermata and Mollusca, the state of affairs is worse. We have already pointed out that the Echinodermata are characterized by having calcareous plates embedded in the skin, but these plates preserved in fossils tell us nothing about the internal organs or about the outside surface of the skin, which in living Echinoderms is most characteristic and of great functional importance to the animal. The class Mollusca includes all the shell-fish (snails, whelks, periwinkles, top-shells, limpets, clams, mussels, cockles, oysters, etc., as well as the octopus, cuttle-fish, and pearly nautilus). In this class the skeleton is represented by the shell, which, like the skeleton of the Arthropoda, is a hardened exudation, but it is an exudation from a very limited area of the skin known as the "mantle," and from a study of living Mollusca we know that quite similar shells can house totally different kinds of animals. In other classes where there is no skeleton, palæontology leaves us completely in the dark, as, for instance, in the great class of the ringed worms (Annelida), to which our own familiar earthworm belongs. Traces of Annelida comprise the oldest fossils known. They have been discovered in the red "Torridonian" sandstone of Scotland and Shropshire, which is millions of years older than the oldest Welsh slates in which the remains of the earliest Arthropoda are found. But all that is left of these ancient worms is their burrows, and what can these tell us of the structure of the animals which once inhabited them?

The record of evolution deduced from embryology, however, gives an outline of the past history of every kind of animal, whether that animal possessed a skeleton or not, and of the internal organs as well as of the external ones. It is, as we shall see later, the only source of our knowledge of the past history of man.

It is, however, to be noted particularly that animals have other ways of reproducing themselves besides the development from the egg. The lowest of all (Protozoa) multiply by dividing into two, and this method is occasionally employed by animals much higher on the scale, such as worms. Other animals, such as the coral polyps and the sea-mats (Polyzoa), give off buds like plants, but in these forms of development there is little or no trace of recapitulation, which is almost entirely confined to development from the egg.

CHAPTER VI

THE MEANING OF RECAPITULATION

It is a startling and fascinating thing for the young biologist once he becomes convinced that a blurred and imperfect record of past evolutionary history is really locked up in each type of life history. It has acted in past time as a great spur to the imagination; in our own young days the main preoccupation of each young researcher was to elucidate and describe some new type of life history and to speculate on its ancestral meaning. Few, if any, paused to ask themselves the question, What does recapitulation imply about the nature of development? We have seen that an animal does not hand on to its germ a minute picture of its own adult structure; the complete proof of this negation is one of the great achievements of the twentieth century, and will be described in a later chapter. The baby receives from its mother powers of growth and powers of movement. These powers may be compared to memories, and the comparison is not a fanciful one, but embodies something real. The word " memory " is used in two quite distinct senses, which may be distinguished as " sensorial memory " or recognition and " habitual memory." Sensorial memory consists in the recall of past scenes and experience which flash before the imagination and are compared with present experiences. A dog of the combative Irish terrier type, ready to fight with every dog he meets, will nevertheless enter into an interchange of friendly sniffs with a dog of the kind he has been brought up with as a puppy. Sensorial memory, greatly developed, forms the background and continuity of the life of our own souls. Habitudinal memory, on the contrary, means the retention of acquired ability. By means of painful effort we learn when we are young to play a skilled game like tennis. It often happens that in middle life we have no opportunity of practising it; but later when we have earned more leisure we may again begin to play it, and then we shall find that a part, but not all, of the skill which we had when we were young has returned to us. Now, in the clearest and best cases of recapitulation which we encounter, the young animal has different habits from the adult one—*i.e.*, has a different way of moving, of finding its food and of escaping from its enemies; in a word, it plays a different game. This game, however, resembles closely the game played by other animals which represent the ancestral stock from which that particular animal has been derived; so that what is reproduced in development is primarily the revival or recall to habitudinal memory of past habits, and only secondarily of former structure. Development, then, may be compared to a recall to memory of the game played by ancestors, and these memories are recalled in a definite order: first come the older ones, and then the newer memories, culminating in those of the activities of the immediate parent, and when these emerge the adult stage is said to have been reached.

We have said that this succession of habits is only evident in the clearest cases of recapitulatory development, and this leads us on to a most important subject—viz., the two great types of development, the embryonic and the larval. A young animal which moves freely about and supports itself is termed a "larva," but when the young animal is enclosed within an eggshell and provided with food for its development, or when it is sheltered within the womb of its mother and feeds on her blood, it is called an "embryo."

The most familiar example of the larval type of development is found in the tadpole of the frog; the chick within the shell provides an example of one type of embryo, and the human baby in the womb of the mother with another. Now, there are two points which clearly emerge from a study of comparative embryology: first, that in every life history there is a larval phase and an embryonic phase, and, secondly, that the larval phase is primary and that the embryonic phase has been secondarily derived from it.

The beginning of development is the egg, which in its general structure resembles Amœba, simplest of animals. But the egg is never thrust forth naked into the world. Immediately after uniting with the spermatozoon, it forms an eggshell, the so-called "vitelline membrane," which is a thin, elastic covering, within which the egg, protected against the most damaging influences of the environment, pursues the earliest stages of its development. During this period it is an embryo. Even amongst the Echinodermata, which have the most primitive larvæ known, the eggs at first become embryos. On the other hand, no animal, when it finally emerges into the world, is exactly like its parent; it still has to grow, and during this growth it alters its shape and to a certain extent its habits, and this period of growth is a larval phase. Our baby boys and girls, in their crawling on all fours and in their tottering gait when they begin to walk, resemble the apes, and especially the gibbon. So that it may be said that the latest page in development is always larval, and that the first page has become embryonic.

But the best proof that the larval phase is primary and the embryonic phase secondary is obtained by comparing nearly allied animals in which these phases are of different relative lengths.

All are familiar with the fact that ordinary frogs and toads all over the world begin life as tadpoles swimming in the water and breathing by gills. But in the West Indies there is found a peculiar little tree-toad called Hylodes, which lays comparatively large eggs far from the water. From these eggs there emerge, not tadpoles, but "froglings." Nevertheless, if we open the covering of these eggs halfway through their development, we find inside each a tadpole with gills and tail complete. The gills and the tail have no function to perform in the embryo, but the tadpole requires the gills to breathe with and the tail to propel itself about. Hence we conclude that the gills and the tail were acquired by the tadpole and handed on to and preserved by the embryo.

This pushing of the earlier fish-like stages of development back into the embryonic phase went on on a great scale as our ancestors became accustomed to drier places and to life far from the water. Yet larval organs are extraordinarily persistent even when pushed back into the embryonic phase; in one stage of growth of the human baby within its mother's womb, its head and body present an extraordinary and grotesque resemblance to the early tadpole of the frog, but the belly is distorted out of all recognition by becoming modified into a huge sucker called the "placenta," applied to the surface of the womb, and able to absorb nourishment through the womb from the mother's blood. If, therefore, we wish to understand recapitulation, we must concentrate our attention on larvæ. The larval stage of one animal corresponds closely to the adult stage of another, and therefore we draw the momentous conclusion *that evolution has fundamentally consisted in the acquisition by an animal when it had reached the adolescent stage of new habits, whilst the original habits persist during the younger stages of life.* If we can justify this thesis, we hold that we have laid bare the real inner nature of biological evolution.

CHAPTER VII

WEISMANN

In the last chapter we endeavoured to sum up the arguments which indicate that the meaning of the recapitulation embodied in life histories is ultimately a record of a series of changes of habits which the race underwent. Now changes of habit take place in living animals usually when they are still comparatively young, but when their powers are fully developed—that is to say, in the adolescent stage. These changes are due to necessity and opportunity. Thus rabbits imported from England have learned in Australia to climb trees; sea gulls, whose normal food is fish, have become accustomed during stress of weather to following the plough and picking up the worms and insect larvæ which it lays bare. Different habits contracted early and long persisted in alter the structure of the body, as is exemplified by the arms of the prize-fighter or the great barrel-like chest of the opera singer. Now what we have implicitly assumed in the previous chapter is that the offspring of such altered animals, exposed to the same circumstances as their parents, acquire the parental habits more easily and earlier than did their parents, and that the structural alterations become more pronounced. In a word, "habitudinal memory" persists from parents to offspring. After the changed habits have persisted for a long time the changed structure appears on the very slightest action of the external circumstances, and finally independently of the external environment before this has had time to act at all. This view, of the truth of which we hope to convince our readers, is essentially that put forward by Lamarck in his *Philosophie Zoologique* 120 years ago. It was accepted by Darwin as one of the causes of the "variation" on which natural selection worked. The reasons why he did not regard it as the sole cause were first that as, already mentioned, he regarded the monstrosities which crop up in domesticated animals as fair samples of the "variation" which takes place in wild nature, and secondly that the direct evidence of actual "lineage series" of fossils as that of the ancestors of the horse was not available in his day. The actual course followed by evolution was in his time merely a matter of wild guess—and hence the fact that it followed step by step the change of habits was not appreciated.

But the German naturalist Weismann denied Lamarck's view root and branch, and Weismann's work is popularly supposed to be conclusive. True there is a large and increasing number of biologists who refuse to be convinced by Weismann's reasoning, but his theory still haunts like a dark nightmare or "Freudian complex" the minds of many of the older naturalists. We shall therefore give an account of it and leave our readers to judge between Weismann and Lamarck.

According, then, to Weismann, the cells which are going to become the germ-cells are set aside early in the development of the egg, and throughout their whole growth and ripening are quite incapable of being influenced by the other cells which form the body, so that no modification of this in the way of changed habits can in any way effect the germ-cells.

Now Weismann held as strongly as Darwin that evolution was due to natural selection acting on continuous variations. How, then, did he account for these variations? To understand this we must plunge a little deeper than we have hitherto done into the structure of the cell.

We have learnt that the lowest animals may be compared to little naked drops of living matter, or protoplasm, and that the bodies of higher animals are marked out into sections by thin walls of dead matter, each section resembling the body of a lower animal and being termed a "cell." Now, inside each cell there is a rounded body termed the "nucleus." This nucleus, when the cell is stained with dyes, retains the stain longer than any other part of the cell, and this method is commonly used to make the nucleus apparent, for it is often quite invisible in the living cell. The nucleus is the centre of the life of the cell; if it is removed the cell lives on a short time consuming its own substance, but it is unable either to digest food or to build up food already digested into new protoplasm. Since the essence of reproduction is the growth of a small part, so as to resemble the whole from which it has been cut off, it is natural to find that the nucleus is closely related to reproduction. When the cell is about to divide, it is the nucleus which first divides. The male germ-cell or spermatozoon is nothing but a nucleus, to which is attached a vibratile hair or flagellum, which it drops when it enters the egg to effect fertilization. This fact is the corner-stone of Weismann's theory. The whole of the potencies of the father's heredity must be carried by this minute nucleus, and since the father is just as powerful as the mother in stamping his image on his offspring, Weismann concluded that it was the nucleus both in the male and in the female germ-cell which was the real organ of reproduction. Now when the structure of the all-important nucleus is closely examined, it is found that not all of it has the power of absorbing stain. This power is confined to certain bars or rods of thicker and denser protoplasm termed "chromosomes," which become apparent each time the nucleus is about to divide. There is always the same number of chromosomes in each cell of the body of every species of animal, but the number varies from species to species so that this number is a valuable species mark.

The first trace of the division of the nucleus is the splitting of each chromosome lengthwise; each half then goes to one of the two daughter nuclei, and so each daughter nucleus has the same number of chromosomes as the parent one. But at one point in the history of the ripening of the germ-cells the number of chromosomes is reduced to half; this is effected by a division termed the " reducing " division, in which the chromosomes do not split; but half of them go to one daughter nucleus and half to the other. When the two germ-cells unite in fertilization the original number of chromosomes is restored.

Now Weismann assumed that the chromosomes, which are always so carefully and evenly distributed at each division, were the actual bearers of the hereditary qualities. He further assumed that each chromosome, which he called an "idant," contained all the powers necessary to build up the complete organism; nay, more, that the idant consisted of several portions, "ids" placed end to end, each of which possessed these powers. But the various ids were not quite alike, and the actual form of the organism which developed from the fertilized egg was a resultant or compromise between the powers of the various ids. As the egg developed and its nucleus divided, the ids, of course, divided, but *except in the case of the divisions leading to the formation of the future germ-cells,* the divisions, although apparently resulting in like daughters, really gave rise to unequal nuclei with different powers. Thus at one division Weismann supposed that the potencies which built up the left side of the body were separated from those which built up the right side, and so on. In this way the ids were resolved into "determinants," each determinant having the potencies capable of forming an organ of the animal. The determinants became similarly resolved into "biophores," and the biophores in the nucleus of each ultimate cell determined what that cell should be, as, for instance, a muscle-cell, or a nerve-cell.

If the reader has followed this description he will have gathered that in Weismann's eye each id has a wonderful architecture, and that it consists of a complicated series of determinants arranged in a definite order, each determinant in turn consisting of an equally intricate arrangement of biophores. In a word, each id is a minute picture of the anatomy of the whole animal; thus Weismann, without realizing it, revived with other names the views of the so-called " evolutionists " of the eighteenth century. Now when the egg undergoes its reducing division it is split into two cells of very unequal size—viz., a large one and a very small one. The large one retains the name of egg, the small one, which is destined to perish, is called the " polar body." Each contains half the total number of ids, but all the ids which pass into the polar body are lost. Since the ids, as we have seen, are not quite alike, and as Weismann assumes that the reducing division takes place at random, it follows that a slightly different sample of the ids may be produced in each ripening egg, and each egg will therefore give rise to a rather different organism. Thus Weismann explains variation. It is a tissue of daring and gigantic assumptions which only a Teutonic mind could have conceived.

But what is the ultimate cause of the assumed difference between the ids? When Weismann was pressed on this point he was at a loss to give a satisfactory answer. Eventually he suggested that these differences were due to the different reactions to the environment of the one-celled ancestors of modern many-celled animals, thus falling back on what we may term the Lamarckian explanation. Why Lamarckism should be valid in the case of the small, primitive animals and not in the case of the larger ones, Weismann did not explain.

THE ARGUMENTS AGAINST WEISMANN'S THEORY

The progress of biological science has proved fatal to Weismann's theory. If the reader has followed the description in the last chapter he will see that this theory is built upon two cardinal assumptions—viz.: (1) That the germ-cells are set aside early in development, and that the process of the building up of the body consists in a simplification and analysis of the complex chromosome structure of the egg; only those cells destined to form the germ-cells of the next generation retain this structure intact; (2) that each chromosome has in it the powers necessary to build up the body, though each if left to itself would give rise to a slightly different kind of body from its neighbour, and that the " halving of the chromosomes " at the ripening division of the germ-cells is a random process.

We shall take the first point first. It is perfectly true that in many animals, especially small ones with short lives, the cells destined to form the germ-cells can be recognized at a very early stage of development. But no differences between the nuclei of these cells and those of the body can be detected; such differences as can be observed are found in the protoplasm of these germ-cells, which seem to have a richer supply of nourishment than that accorded to ordinary body cells. In other animals the germ-cells can be detected only at a much later period of development and in our own phylum (Vertebrata) a most marvellous state of affairs has been discovered. Germ-cells appear in the embryo very early and go through all the stages of ripening, but these cells undergo degeneration, and are absorbed before the animal grows up. The germ-cells which actually survive are developed later from one of the body-tissues—viz., the lining of the body-cavity or peritoneum. A most wonderful instance of this has been observed by Dr. Crewe, head of the Animal Breeding Department of the University of Edinburgh. A hen which had laid many broods of eggs, from which chickens had been reared, began in old age to assume the plumage and manners of a cock. This bird actually succeeded in "treading"—that is, fertilizing—other hens, which then laid eggs, from which chickens were reared, so that during the course of its life it was first a mother and then a father. When it was killed it was found that the ovary or egg-producing organ had been destroyed by disease, but that a testis or spermatozoon-producing organ had been budded off from the cells lining the body cavity.

One of the most brilliant of living German biologists, Hans Driesch, attacked Weismann's position in another way. He experimented with the eggs of Echinodermata, which are produced in enormous numbers, and which are easy to rear during the first stages of their development. By shaking and other methods he was able to separate the first cells into which the egg divided. According to Weismann's view, each of these cells ought to have been endowed with the power of building up only a particular portion of the embryo, but Driesch showed that each of the first eight cells into which the embryo divided could give rise to an embryo of diminished size complete in every detail. Driesch further squeezed eggs which had divided into eight cells between two glass plates so as to displace the cells from their normal position, so that those which should have been in front were at the side, and so on, and yet these deformed eggs gave rise to perfectly normal embryo.

It is true that in eggs of other animals, as, for instance, in those of the ringed worms (Annelida) and the shell-fish (Mollusca) separated cells develop only into portions of the embryo, but it has been shown that this is due not to any difference in the nuclei but to differences in the protoplasm. The protoplasm in these cases, as Driesch expressed it, is "stiffened"—*i.e.*, precociously moulded into the minute structure of the tissues to which it is due to give rise, and so when the cell is separated from its fellows it cannot be moulded by the nucleus into a complete embryo.

Other workers, such as Spemann and Lewis, have brought valuable evidence in support of Driesch's views from later stages of development. Of this we shall give one instance. The eye of a Vertebrate, such as ourselves, is made up of two main parts—the retina and the lens. The retina, the sensitive surface on which images of objects are formed, is an outgrowth from the brain; the lens, by which the light is concentrated on the retina, is a devolpment of the skin on the side of the head. In a young tadpole, in which the retina is a mere stud on the brain and the lens is not yet formed, if the skin of the back be slit open, it is possible to cut off the rudiment of the retina from the brain. If this rudiment be pushed back under the skin into the region of the shoulder, the flaps of cut skin will heal up, and the retina will continue to develop. It will then force the skin of the shoulder to develop into a lens, although never in the history of the race have lens been formed in this position. From this and similar evidence we draw the conclusion that all the nuclei of the embryo are potentially alike and that each possesses the power to produce the whole animal, but that what part of the powers will be brought into action depends on the surroundings in which it finds itself.

(2) Variation was supposed by Weismann to be due to the random casting out of half the ids at the reducing division. Now modern research has rendered the idea of the "random" reduction of the chromosomes number quite obsolete. The chromosomes in a nucleus are not equivalent to one another; on the contrary, they form a regular set of organs of definite size and shape. Of each kind of chromosome there are two representatives—and one of these is derived from the nucleus of the father germ-cell and one from that of the mother germ-cell when these two met in fertilization. In the reducing division, corresponding paternal and maternal chromosomes pair with one another and then separate from one another, the paternal chromosome going to one daughter nucleus

and the maternal one to the other daughter, so that each nucleus receives a sample of each kind of chromosome. A random "casting out of the ids" is therefore out of the question. It is true that it is assumed —without any evidence—that one nucleus may receive the maternal chromosome of one pair and the paternal chromosome of another, so that different combinations of maternal and paternal chromosomes may be distributed to the two daughter nuclei at the ripening of different germ cells. In this way it is attempted to account for the different combustions of the qualities of the father and mother which are seen in a family when the parents are unlike each other. But in this way only intermediates between father and mother can be accounted for—the original difference between the parents (independent of their sex) which constitutes the essence of variation is left unexplained.

Weismann's theory therefore fails at all points where it is experimentally tested. It is true that Weismann further asserted that he had disproved the inheritability of acquired characters, but the experiments which he relied on to substantiate this negative result can only be described as utterly childish. He cut off the tails of white mice and bred from these mutilated individuals, and triumphantly proved that the young mice were born with tails! It can only be surmised that Weismann had never read Lamarck. For what Lamarck said was that the environment acted on the animals not directly, but by producing new needs, to which the animals responded by fresh efforts. These efforts led them to use some organs more and others less; those used more increased in size, whilst those used less diminished. It was according to him this use and disuse continued over long stretches of time, and that eventually led to changes of structure—that is, to transformism or evolution.

CHAPTER VIII

THE INHERITABILITY OF HABIT AS THE REAL CAUSE OF EVOLUTION

In the preceding chapter we have shown how lamentably Weismann's theory of the origin of variations breaks down when put to the test of facts. We have also shown that the study of closely allied races, of lineages of fossils, and of embryology, all suggest most strongly that changes of habit are the real causes of changes of structure. It is common knowledge that changes of habit within the lifetime of the individual do produce slight changes of structure, but the vital question arises whether these changes of structure are handed on to the next generation or not. Within the last twenty years some positive evidence has been produced that this is indeed so; but it must be remembered that all the evidence of palæontology goes to show that evolutionary changes are extremely slow, and that the chances that a measurable change would show itself within the span of a human life are very small. Nevertheless, some superficial characters vary very much from species to species, and there is hope that these characters might show an inheritable reaction to environment within a limited number of years. Of these hopeful characters, colour (pigmentation) is the most variable, and it is precisely in respect of colour that the most striking results have been obtained.

Dr. Kammerer, to whose work we have already alluded, performed the great standard experiment. The common fire salamanders of Europe have black skins diversified by yellow patches. These animals were kept by Kammerer, after they had emerged from the water in which they spend their tadpole stage, in boxes with yellow walls and with their floors covered with yellow loam. These animals require four years to grow up; during this time the yellow patches increased in size and became connected with one another, so as to form two longitudinal bands.

When two such animals were paired together and their young reared under the same conditions, they were much yellower than were their parents at the corresponding stage of development, and when they became adult they were almost completely yellow. If the salamanders were kept in black boxes the yellow patches diminished in size as maturity was reached till only a few were left. When a second generation was reared under the same circumstances these spots disappeared, and the animal became a nearly exact copy of the allied species, *Salamandra atra,* which lived in the upland pastures of the Alps.

As indicated in a previous chapter, a great controversy has been raised over the reliability of Kammerer's results; it is, therefore, gratifying to be able to record that these results have been confirmed by another zoologist working on different material. Dr. Durkhen of Breslau found that when the caterpillars of the common cabbage white butterfly (*Pieris brassica*) were exposed to orange light, they developed into pupæ in a large proportion (66 per cent.) of which the white colours of the cuticle were suppressed and the green blood of the chrysalis shone through. If these pupæ were allowed to develop into butterflies and these butterflies were paired, and the eggs laid allowed to develop into another generation of caterpillars, and these caterpillars again exposed to orange light, then the proportion of green caterpillars increased to nearly 100 per cent.; whereas if the caterpillars were subject to ordinary daylight still about 34 per cent. turned green, a number enormously greater than that found in Nature. These experiments have been repeated by Professor Heslop Harrison and completely confirmed. In some other cases the inheritability of acquired habit has been proved, though the new habits did not lead to a change in structure. Thus Pavlov trained white mice to come out of their cages when a bell was rung in order to get food. It required 300 lessons to train the first generation to do this, whereas the fifth generation required only 30 lessons. Professor McDougall of Harvard obtained similar results with rats, which were trained to avoid landing on an electrified board. Professor Harrison proved that saw-flies after a period of years could be trained to lay their eggs on other species of plants than those to which they are accustomed, and that when these eggs are allowed to develop into saw-flies, the flies emerging from them will choose the new plants to visit instead of the old ones proper to the species, even when the opportunity to visit both is provided.

The present state of the question, then, is that the evidence available points strongly in the direction of acquired habits being inheritable, and that the structures associated with them are inheritable too. This does not mean that the progeny will show the new habit without the stimulus which called it forth in the parent, but merely that the young will acquire this habit more easily and with a slighter stimulus than did the parents. After perhaps thousands of generations the habit or the structure associated with it will appear independently of the stimulus altogether, but to reach this consummation a very long time is required.

As we have seen, this direct evidence confirms the indirect evidence derived from systematic zoology, palæontology, and embryology, and therefore we hold that it is valid, and that here we have the cause of the variation which leads to evolution. But some might object that the change of habit is just as much a "spontaneous variation" as a change of structure. But this view is totally opposed to the available facts. New habits arise under the stress of new necessity and new opportunity, or, as Lamarck phrased it long ago, in response to new needs. There has been a tendency amongst a certain school of naturalists to regard animals as automatic machines—or as mechanical Jack-in-the-boxes, in which a certain type of stimulus or change in the external world produces always the same response. But this view will not stand investigation. "An animal," says McDougall, "though its activity may be roused by a stimulus, develops an activity which is directed towards an end and which persists until this end is attained or the animal falls exhausted." If it does not attain the end by one method it will try another. The cut-out organ or tissue of an animal, so long as it retains life, exhibits nothing of this purposeful striving, but does really act very much as if it were a piece of machinery, and it is this fact which in our judgment has misled physiologists and has induced them to seek a purely mechanical explanation of life, since nearly all their experiments are performed with cut-out tissues, not with intact animals.

But we know from our own experience how this automatic action develops in our own bodies. When we learn the piano we engage in a series of efforts of each of which we are distinctly conscious, and each of which might be described as a striving or struggle. When the learning is complete we can play the piano mechanically, without thinking of the separate movements of our fingers at all. It thus appears from our own experience—and it is only from this that we can form any conception of the inner life of animals at all—that the automatic action is derived from a voluntary action oftentimes repeated.

The best example of the recent formation of an entirely new habit is the flesh-eating habit of the Kea parrot of New Zealand. Before the arrival of the English there were no warm-blooded quadrupeds at all in New Zealand—nothing, in fact, but birds, snakes, and lizards. The Kea parrot is an inhabitant of the higher hills; it feeds on the seeds of a bushy plant with small white flowers, which seen from a distance bears some resemblance to the back of a sheep. When sheep were introduced the parrots began to investigate these moving bushes and dug their sharp beaks into the backs of the unfortunate sheep. They fed on the fat thus obtained, and, flourishing exceedingly, persisted in the habit, which soon became an ingrained habit of the species, and the Kea began to extend its range into the plains. The bird became such a serious menace to sheep-breeding that special means had to be adopted to exterminate it.

We must now devote a few words to plants and explain why they furnish so much more unsatisfactory data than animals. So far as closely allied species are concerned, a good deal of evidence has been obtained, but the evidence from palæontology and from development is deplorably weak; the great outstanding difficulty in plants arises from the obvious fact that we ourselves are animals and not plants. We can in imagination make some kind of effort to get inside an animal, especially a vertebrate, and see what inner life is like, but we can form no conception of the inner life of a plant, if it has one. We can have some idea of what function the various organs of an animal perform, but if one plant has narrow toothed leaves and an allied one has broad leaves with an even edge, we do not know what this difference means to the life of a plant. In palæontology no " lineage series " of plants has been discovered—that is, no series of beds in which the same kind of plant ranges throughout the series but undergoes slight changes as time goes on. Further, a plant to be known must show not only its leaves, stem, and roots, but also its flowers and fruit, and these are rarely all preserved, and still more rarely in such relations as to make it certain that the one belongs to the other. In the development of the plant the most critical stages are embryonic and are blurred beyond recognition. Nevertheless, in the later stages of growth, during what is known as the youth of the plant, traces of recapitulation can be detected. In the common gorse, the leaves are absent, and are replaced by hard, green spines; nevertheless, the young plant has normal leaves, which drop off as it grows up. Similarly, in the Australian acacias the leaves are absent, and the leaf stalks are developed into broad knife-blade-like structures, which present their edges to the sun's ray. But these plants when young have normal leaves, which fall off later.

We, therefore, conclude that the theory of evolution assumes as it postulates all the fundamental features of living beings, for it means that the evolving being reacts to the environment, learns and passes its knowledge to posterity. It does not help us in the least to reconstruct some imaginary bridge between living and non-living matter. In fact, if science be defined as the study of the processes which occur here and now, and their imaginary prolongation into the past and the future, then it may be said that all theories of the origin of life are unscientific, and that when the evidence is fairly looked into we are led straight back to a discontinuity, *for in all the processes of Nature now going on, living beings only originate from pre-existing living beings.*

CHAPTER IX

CONDITIONS OF EVOLUTIONARY CHANGE

If we now accept change of habit as the cause of evolution we may learn some interesting things about the circumstance under which the great advances in the structure and activities of animals were made. We find in the beds of the Coal period the first evidences of the existence of four-limbed vertebrate animals, which resembled our surviving newts and frogs, but were very much bigger. In the next period, the Pormian or New Red Sandstone, we find lizards which are dry-skinned animals. How did the change take place? The New Red Sandstone is believed to consist in large measure of deposits of desert sands; the luscious swamps of the Coal period had dried up, and their denizens had been compelled to adapt themselves to dry air. But when the great change had been effected, the race of lizards spread like wild fire all over the world, and adapted themselves to all sorts of situations. From them snakes, turtles, and crocodiles have been derived, and these beasts have many of them gone back to live in water without losing the valuable horny scale (the tortoiseshell) which their lizard ancestor acquired as a protection against drying up in the desert.

The later history of the Mammals or hairy quadrupeds is also fairly well known. A few remnants of small forms no larger than rats have come down to us from the Jurassic and Chalk periods, but they first become prominent in what are known as the Tertiary beds—that is, in the clays, sands, and freshwater limestones which were formed after the chalk. It is from this period that the ancestral histories of the horse and of the camel have been recovered. Now it can be shown that all the higher types of Mammal appeared in the North, and spread in successive waves over the rest of the world, overwhelming and extinguishing the lower types. In the North, where conditions of life were harder, where the animal had to make a greater effort to meet them, there the great changes in habit and structure took place, and there evolution really went forward by leaps and bounds.

Mammals themselves, however, seem to have originated earlier, not in the North, but in Africa, and in the South of this continent there was in New Red Sandstone times an ice period, the reasons for which have never been satisfactorily explained. The hairs of mammals are derived from the same part of the skin as the scales of lizards—indeed, they may be regarded as long, thin, overlapping scales, which would be a protection against the cold which these animals had to meet. When this cold period passed away the great lizards spread south again, and the early mammals were hard put to it to hold their own, and there is evidence that they succeeded in doing this by climbing into trees. For this reason, only scanty remains survive from the Jurassic and

Cretaceous periods, but at the beginning of the Tertiary period some great change took place—possibly another cold period—which wiped out the great land lizards. Then the whole world was open to the mammals, and they swarmed in and took possession, adapting themselves to running, leaping, burrowing, and even flying; but the human race is allied to the primitive stock which retained the original habit of living in trees.

If we go back to still more primitive times—viz., to the old red sandstone, which preceded the coal, we find traces of a still more momentous change—viz., that which made a land animal out of a fish and changed fins into arms and legs. The old red sandstone consisted partly of desert sands, like the new red sandstone, and partly of deposits in inland saline lakes. In it are embedded the remains of a great many curious fish of the swamps of Africa and South America. These swamps periodically dry up, and then the fish have to breathe air. The rays of the fins of these old red sandstone fish are long and finger-like, and out of these rays in the next period fingers and toes are developed. It can be shown that the fourth toe developed from the axis of the fin, and the other toes from the side rays springing from it. As these fish were left stranded by the recession of the water they learned to hop over the wet mud and gradually lost the web of the fin, so that the rays were left bare. *Verily storm and stress are the mothers of evolution.*

CHAPTER X

THE EVOLUTION OF MAN

WE now approach the most important of all the questions raised by the evolutionary theory—viz., the origin of the human race. This question must be examined in the light of all the evidence which is used for establishing evolution.

If we have made up our minds to regard every broad resemblance in ground-plan of bodily structure as evidence of blood relationship, then any schoolboy can see that the body of an ape is built on the same general plan as that of a man. But this is to beg the question, and we therefore fall back on our three great criteria of evolution—viz., (*a*) the comparison of allied races, (*b*) the study of fossils, and (*c*) embryology. Now, human races differ from one another in many points of structure, but none of these points diminish the gap between the apes and man in any perceptible degree. The lower races, who do not wear boots and shoes, have better developed feet and more flexible toes than their civilized brothers, and some of the savage races, such as the Bushmen, have comparatively small skulls, but these skulls are proportioned to their small stature and slender proportions. In the Huxley Museum in the Royal College of Science in London two skeletons, one of a European and the other of a Bushwoman, used to stand side by side. They were different in height, and therefore in the sizes of their component bones, but one was just as human in appearance as the other.

When we look at the remains of fossil men the evidence is very much the same. No such remains are known from beds older than the onset of the great Ice Age. If man is descended from an ape-like ancestor, then it looks as if he were made by the Tertiary Ice Age, just as we have seen that in all probability the old Ice Age of new red sandstone times made a mammal out of a reptile. As we search through the various filled-up swamps and river gravels deposited since the last Ice Age, we find here and there the skulls and sometimes the complete skeletons of prehistoric man. We can trace their arts—*i.e.*, their tools and utensils—back to their primitive beginnings, but the men themselves had skulls which would not have disgraced an educated European of to-day. At last, however, we get back to the last great extension of the ice. The ice period seems to have been made up of four or five periods of terrible severity with enormous extensions of the ice-sheets, separated by much milder times, during which the ice receded. The last extension is known as the Magdalenian or Wurmian ice period. Between this period and the previous cold phase, which is called the Reissian ice period, there was a mild interlude, and amongst the gravels deposited during this time the remains of an early human race have been found. These are widely different from anything we can see in modern man. The first of these remains was found in Lorraine in a cave in the valley of the Neander, a tributary of the Meuse, whence the race was called "Neanderthal man." Afterwards complete skeletons were found at Le Moustier in the south of France, and the name "Moustierian man" is, perhaps, more usual to-day. Other remains of the same race have been found at Gibraltar, at Krapina in Austria, and in Palestine, so that quite evidently the race had a wide extension. The first remains discovered consisted merely of the caps of the skulls, showing the eyebrows and the upper parts of the orbits. From these fossils Huxley concluded that Neanderthal man was, indeed, the "missing link" between man and the apes. The huge bony eyebrow ridges resembling those seen in the skull of a chimpanzee, and the low, flat brain-case, seemed to bear out this view. But the far more complete remains found at Le Moustier put a different aspect on the case. It transpired that the brain-cases of these men were actually more capacious than those of the average European, but that their heads drooped forwards between their shoulders, so that the muscles attaching them to the necks were placed higher up than in modern men, and thus Huxley was mistaken in his starting-point for measurement. The face, with its great eyebrow ridge and mask-like cheek-bones, was extraordinarily ape-like, but the teeth, like those of modern man, were in an even row; there were no projecting eye-teeth as in apes. True, the teeth had large, persistent pulps, which indicated an enormous capacity for growth and repair, doubtless necessitated by the tough food; but this capacity would be warmly welcomed in these days of bad teeth and expensive dentistry. The thigh-bones of Moustierian man were curved, which indicated that these men did not stand quite upright and had a shambling gait, and the big toe was widely separated from the other toes, so that possibly the foot still retained some powers of grasping. In respect of their limbs and faces, this race was undoubtedly ape-like, but their brains were thoroughly human.

The only remains of organisms which may possibly be older than Neanderthal men have been found at three different places, and these remains tell us little or nothing about the beasts which produced them.

1. There are two very fragmentary skulls from Piltdown in Sussex; about these one of our greatest biologists has said that, unless they had been human, no one would have paid any attention to them; they are so hopelessly shattered. Indeed, the attempt to reconstruct them has led to violent controversies, so that one anatomist said that the capacity of the brain was 1,500 cubic centimetres (which is that of an average European), whereas another estimated it at 1,000 cubic centimetres, which is the size of the brain of a native Australian woman. Opinion seems to be settling down to an estimate of about 1,200 cubic centimetres. Little or nothing of the face is preserved, but it seems clear that the Neanderthal eyebrow ridges were absent. A very great difficulty in connection with the first Piltdown skull is the lower jaw, which was found some little distance from the rest of the skull. As the reader may have gathered, so far as the face

has been reconstructed it appears to be much more modern in aspect than that of Neanderthal man. The lower jaw, if it belongs to the skull, is unique in possessing a great pointed eye-tooth projecting beyond the line of the other teeth, like that of an ape. Some authorities believe that it is the jaw of an ape brought into accidental proximity to a human skull.

2. A human lower jaw has been found in a quarry at Heidelberg, seventy-five feet below the surface; this is much more strongly built, especially at the hinge, than a modern human jaw, and its possessor was evidently a good masticator, but beyond this we know nothing about him.

3. In the gravels of a river in Java there have been found remains which have been regarded as human and have been labelled Pithecanthropus (literally, Apeman), and which some authorities consider to be the veritable missing link at last. Their discoverer, Dr. Dubois, after exhibiting them at the International Zoological Congress of 1898, withdrew into retirement in Holland, and, under the influence, it is stated, of the Roman Catholic Church, refused to allow the fossils to be examined by any other scientific man. Casts, however, and drawings have found their way into the various museums.

The remains consist of a cap of a skull less extensive than the cap of the Neanderthal skull examined by Huxley, a thigh-bone, and two back teeth. The size of brain indicated by the skull has been estimated at 800 cubic centimetres, which would be exactly intermediate between that of the highest ape and that of an

Australian woman, but more modern estimates put it at 1,000 cubic centimetres. The molar teeth show some peculiarities reminding us of the molar teeth of apes. but the thigh-bone is perfectly straight and seems—if its possessor was a man—to indicate a completely upright gait. The remains were not found together, but separated from one another by a distance of several yards. If they really belonged to the same creature, was he a man? We have already seen that Neanderthal man with a big brain had, nevertheless, a shambling gait, and Neanderthal man made tools. Now, it has been argued with great force that one great factor in man's early development was the attainment of the upright posture, which set free the fore-limb for tool-making and for other skilled operations necessitating close observation and judgment. Is it really credible that a being like Pithecanthropus, with a brain only about half the size of Neanderthal man, and who apparently did not use tools, should have completely attained the erect posture? In our judgment it is not credible, and we are therefore inclined to regard with favour the views of other authorities, who regard Pithecanthropus, not as the remains of a man at all, but as the bones of a gigantic ape belonging to the same race of apes (the gibbons) which now inhabit Java, for these apes have straight thigh-bones.

When, however, we turn to the evidence from embryology, then it becomes clear that the body of man has been evolved from the body of an ape-like creature. For the babe within the womb has the unmistakable rudiment of a tail, and when the baby is born the arms are as long as the legs and have a powerful grip, whereas the legs are feeble, curved, with the soles bent inward, and utterly unable to support the weight of the body. When the baby is about a year old and begins to walk, his whole attitude is surprisingly like that of the higher apes, especially the gibbons. The legs are still bent, the gait is tottering, and the arms are held out at right angles to the body like balancing poles. In fact, the one-year-old baby might almost be described as an ape-larva.

But even if embryology, and the proof that evolution in the lower animal world has really occurred, lead us to believe that the human body has gradually grown out of the ape body, there remains unsolved the question which is the only really important one—*i.e.*, the origin of the human soul and personality. Did the human soul, like the human body, gradually grow out of the ape soul, keeping pace with the development of the brain? Or are we here in presence of another discontinuity like that which occurred at the beginning of life, a discontinuity to be accounted for, as Wallace, co-author with Darwin of the theory of evolution by natural selection, thought, by a fresh outburst of the Sublime Creative Power which fashioned the universe?

The solution of this question lies outside the province of zoology altogether, and involves questions of philosophy and psychology with which the zoologist, as zoologist, is incompetent to deal. If we consider the mind as a mere name for the functions of the material organ known as the brain, then we shall naturally conclude that the human soul is a gradual development from the ape soul. But this view, so plausible at first sight, involves, when consistently thought out, such enormous difficulties and contradictions that Huxley himself denounced it as involving grave philosophical error, and openly stated that he was unable to conceive of matter without the existence of mind to picture it. The shallow anatomist or physiologist who asserts that mind is only the action of brain forgets that the reality of his own mind is the unconscious postulate of all his knowledge, and that all that he knows of matter consists simply of presentations to or images in this mind. From social intercourse he learns early to infer the existence of other minds like his own behind some of the moving objects (his fellow-men whom he encounters), but this knowledge is secondary and derivative as compared with his primary knowledge of his own mind. A profound modern philosopher, Bergson, has put forward the view, which we think far more reasonable, that the material brain is merely a gigantic telephone exchange—a meeting-place for wires receiving messages from the outside, and other wires conveying messages to the muscles, amidst which is seated the Mind, which operates this exchange as it wills, making the connections necessary for carrying out its purposes.

Even on Bergson's view, however, the ape soul might have grown into the human soul, and it certainly cannot be proved that it did not, but there are some facts which give us reason to pause before coming to this conclusion. We have seen that the oldest race of men which we know anything about are the Neanderthal men, and that these people were undoubtedly ape-like in their faces and limbs. But in spite of their shambling gait they made tools, and they buried their dead, putting in the graves the implements which they used during life. This custom, all anthropologists agree, implies a belief that the soul survives bodily death!

Much has been written recently about the supposed evolution of the belief in immortality in ancient Egypt. It has been supposed to be due to a mistaken interpretation of the natural preservation of the body when buried in the hot sands of the desert. But all such theories are vain in view of this light on the minds of the most primitive men known. Evidently a belief in the reality and survival of the soul is a fundamental part of the human mental equipment and has been so from the beginning, and, however occasionally suppressed, is always subconsciously there, buried deeply in the recesses of our being.

If, therefore, we choose to believe in a discontinuity between the animal and human souls, there is nothing in zoology or palæontology to prove us wrong.

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HEREDITY

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TO

JULIAN HUXLEY

WHOSE DEEDS AND WORDS HAVE DONE SO
MUCH TO CREATE IN THE POPULAR MIND
AN EARNEST DESIRE TO KNOW MORE
ABOUT THIS SUBJECT

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HEREDITY

CHAPTER I

THE GERM-PLASM

THE individuals of a generation grow old and die, and so it is that, if the race is to endure, there must be a continual production of new individuals to take the place of those who predecease them. Life, it would seem, can only spring from life itself, and is transmitted from one generation to another through the exercise of the function of reproduction as a torch is passed from runner to runner in an unending relay.

The origin of a new generation can be studied if the life-history of an individual, of a man, for example, is traced backwards to its beginning. If this is done, it will be found that before the adult man there was the youth, the infant, the fœtus, each of these smaller than the last, but all having the same general form and being recognisably human. Before the fœtus, however, the individual in appearance was so different as to merit a different name, an embryo, at one time quite spherical and consisting of but three layers of cells. Still earlier, there was but a single layer of cells. Before this there was but a mass of a few large cells, and at the beginning of all there was but a single large cell, with its controlling nucleus. This single large cell was the fertilised egg in which the individual and also the new generation had their origin.

The cell is the architectural unit of the body. It consists of a mass of living stuff contained within a wall, and when properly killed and stained, it is seen that its contents are not homogeneous but consist of living and of non-living matter. In it there is an area which picks up stains more readily than the rest and which can be shown experimentally to be the controlling centre for all the living processes of the cell. This is the nucleus.

This fertilised egg is specific to the highest degree and embodies all the possibilities of individual development and of racial perpetuation. Through its continued division, growth and the increasing complexity of the multicellular body that results are made possible, leading to the attainment of a relatively stable and balanced state which we know as maturity, and thereafter to instability, senility, and death.

It is established that to this fertilised egg each of the sexually distinct parents contributes but a single cell, so minute as to be beyond the limits of the unaided eye, and yet these two cells—the marrying cells, the gametes, the egg elaborated by the female and the sperm provided by the male—are the only material link between the generations, and across this narrowest of bridges everything organic that one generation can bequeath to its successor must pass. Such sexual reproduction, the fusion of dissimilar gametes, consists in the union of two cells which, though at the time of their fusion are independent and detached, were at an earlier stage of their own history part and parcel of the bodies of other individuals of the species to which the parents and the future offspring belong. It is established that the essential feature of this sexual fusion is the union of the nuclei of these cells and not of the cells themselves, and that the difference in size and form of the gametes is of but secondary importance. It is reasonable to assume that the size and food content of the egg serve to give the embryo a good set-off in life, and that the size and shape of the sperm make for motility which ensures that the gametes shall meet, that fertilisation shall occur, and that a new individual shall be conceived.

The size of the egg varies enormously in different animals. In birds the food content of the egg forms the sole supply of the young during the earlier stages of its independent existence, and the egg is very large in comparison with the size of the female that lays it. In mammals the young do not follow independent lives during infancy, but are, as it were, parasitic upon their mothers, getting food from her and not from the egg, and in these cases the egg is minute and contains only a sufficient quantity of food material—yolk—to carry the zygote over to the stage at which it develops processes for attaching itself to the wall of the mother's womb.

The beginning of the development of the individual takes the form of the division of the fertilised egg into two daughter cells, and this process of cell-division is the basis of all growth. When a cell, any cell, is about to divide, the wall of the nucleus breaks down and its contents change from their chiefly fluid state into a number of solid rodlike bodies, called, since they take up stains eagerly, chromosomes. For the same reason, the material of which the chromosomes are composed is called chromatin. A star-shaped figure of radiating fibrils appears and divides into two to form a spindle with a radiating star at either end. On this spindle the chromosomes arrange themselves at its equator and each divides along its length, then these halves separate and travel one to one pole of the spindle, the other to the other. Finally, the body of the cell, becoming constricted at its equator, divides, and the set of chromosomes at either pole swells up to form a nucleus. There are thus two cells instead of one. Since the cell and its nuclear chromatin are composed of living stuff, the cell itself and the chromosomes grow to attain their original size. This process of mitosis, called so because of the threadlike fibrils of the spindle, ensures that each chromosome is divided exactly longitudinally, and that to each daughter cell a complete set of halved chromosomes is distributed.

It is a significant and noteworthy fact that the number of chromosomes in any species is constant and characteristic of that species. It is, therefore, possible to tell the species to which an animal belongs by counting the number of chromosomes in the nuclei of its dividing cells. This is not all, for since in many cases the individual chromosomes differ among themselves in size, shape, and relative position, it can be shown that they exist in the nucleus in pairs, the members of a pair being similar in size and shape.

There is one significant exception to this rule of the exact halving of the chromosomes and the precise distribution of the halves to the daughter cells, for in one of the cell divisions which result in the elaboration of the gametes in the sex-glands, this splitting of the chromosomes does not occur. Instead, the members of each pair of chromosomes come to lie closely applied one to the other, later they again separate, and the result is that into each daughter cell there passes not a halved chromosome but a whole one, and, moreover, each daughter cell comes to contain only *half* the number of chromosomes that is characteristic of the body cells of the individual and of the unripe gamete. The ripe gametes, therefore, each contain half the number of chromosomes characteristic of the species, and it is only when the egg and the sperm meet in fertilisation that this characteristic number is restored. Examination of the ripe egg and sperm and of the fertilised egg that results from their union reveals that of each pair of chromosomes in the fertilised egg one member has come from the father, by way of the sperm, the other from the mother, by way of the egg.

The fertilised egg exhibits none of those details of form and function which later, when the individual is adult, will allow the observer to describe and to classify it. Yet of two eggs quite indistinguishable one from the other under the microscope, one becomes a tall, blue-eyed, fair-haired boy, the other a brown-eyed, raven-haired girl, of less than average height.

It is agreed that many of the dissimilarities in characterisation exhibited by individuals related by a common ancestry are but reflections of different experience. Stature, for example, is undoubtedly seriously affected by nutritional agencies. It is known that different degrees of density make all the difference to the luxuriance of growth of a plant, that the tree exposed on the wind-swept side of a hill will not attain the proportions of its relative growing in a sheltered park. But there is no evidence of any kind which would allow us to believe that the impress of environmental agencies can turn blue eyes into brown. It would seem indeed that, whilst many of the characters of an individual are but reflections of experience, there are many that are exhibited because they are inborn.

That offspring do in general resemble their parents is so familiar a fact that its significance is either overlooked or over-emphasised. It has long been accepted, without any wonderment, that many characters of the individual are faithfully transmitted from generation to generation, that like tends to beget like, that it can be predicted confidently that any individual conceived will sooner or later exhibit those details of form and of function which characterise the species, the race, even the family to which it and its relatives belong. On the other hand, it has equally long been recognised that no son is the carbon copy of his father, that every individual is the first and last of its identical kind, that variation—*i.e.*, deviation from the average of the stock—is universal.

It may be assumed that, out of the accumulated anecdotes concerning the appearance and reappearance of similarities and dissimilarities among related individuals, there arose quite early in man's history the notion that in their distribution among the generations there were suggestions of an orderliness, a regularity; that the appearance and reappearance of many characters could not be accounted for by similarities in experience, but that these characters were indeed being transmitted in a fashion that was in no way haphazard, but was surely subject to certain rules. Thus it would become inevitable that the human mind in its inherent desire to trace and to describe order in Nature should seek some mechanism which in its functioning could account for this observed orderliness. A consideration of the observed facts of organic inheritance would enable man to form a speculative thought-model of what the architecture of a postulated hereditary material may be. It is of interest to note that it was not until the time of Aristotle that there is on record any serious attempt to formulate any hypothesis to account for the observed phenomena of heredity. One notes also the absence of any attempt to define the organic relation of parent and offspring among primitive peoples.

But with the coming of the microscope, it became clear that in the fertilised egg and in the gametes there must be something that predetermines much of the future individual's structural, functional, and mental limitations. And so the idea of an idioplasm, a special substance within the cell, the function of which was to transmit and to control the hereditary characters in the developing individual, came into being. This idioplasm remained a purely theoretical constitution until the chromosomes were discovered, and then it was seen that many of the functions ascribed to this hypothetical idioplasm could be performed efficiently by the nuclear chromatin.

Then came the theory of the germ-plasm, a substance of definite chemical and specific molecular constitution which was the bearer of the determiners of the hereditary characters. It was taught that a continuity of germ-cells from generation to generation was rare, but that a continuity of this germ-plasm was the rule; that an individual is like its parents, not because the latter produced the former, but because both parent and offspring were produced from the same stock of germ-plasm. It held that the bodies of the father and of the son were but developments at different times of one and the same continuous stream of germ-plasm. The germ-cells, the gametes, were to be regarded merely as incidents in an unbroken line of germ-plasm, which, under certain circumstances, usually the union of two of its constituent cells, frothed up to produce a great excrescence, the body of the next generation, and continued its existence therein. It was taught that the germ-plasm was immortal, having existed from the very dawn of life, whilst the body was mortal, being formed afresh in every generation. It was argued that when the fertilised egg divided, some of the resulting cells became set apart at once and played no rôle in the building of the body of the new individual, but remain quiescent, later to become the germ-cells of this new individual. This great edifice of theory in locating the hereditary units in the then newly discovered chromosomes and in suggesting an apartness of the germ-cells enshrined the truth, though this was not to be revealed for many a year.

Meanwhile, thoughtful inquisitive men were seeking critical methods of demonstrating the existence of this postulated idioplasm. The Abbé Mendel, because of the more skilful planning of his experiments, was more successful than his fellows in collecting and interpreting critical data, and he founded the science which is called in his honour "Mendelism," a scientific theory relating to the distributive mechanism of organic inheritance. Mendel took for his problem the question as to the exact manner in which the fixed and true-breeding varieties within a species are related one to the other. Unlike previous experimentalists in this field, he did not consider the individual as a unit in inheritance, but he concentrated his attention upon the mode of transmission from generation to generation of sharply contrasted characters, such, for example, as the length of stem in the culinary pea—there is a tall pea, and there is a dwarf—or in the colour of the pod, which can be green or yellow. He kept accurate pedigree records showing the ancestry of the characters of each individual in his experiments. He counted the number of individuals in each generation and the numbers of dissimilar kinds, and was able to give an exact mathematical statement of his results. He found that in the case of every one of the seven pairs of contrasted characters of the culinary pea with which he had dealt, the mode of inheritance was the same. Out of his experimentation there emerged very clearly certain verifiable facts, and upon these facts he framed his two laws of organic inheritance. It was clearly demonstrated that, when one or more pairs of such contrasted characters were involved in a breeding experiment, there was in the second hybrid generation an orderly reappearance of those characters in definite numerical proportions. His generalisations or scientific laws refer to the phenomena of (1) segregation and (2) the independent assortment and recombination of hereditary factors.

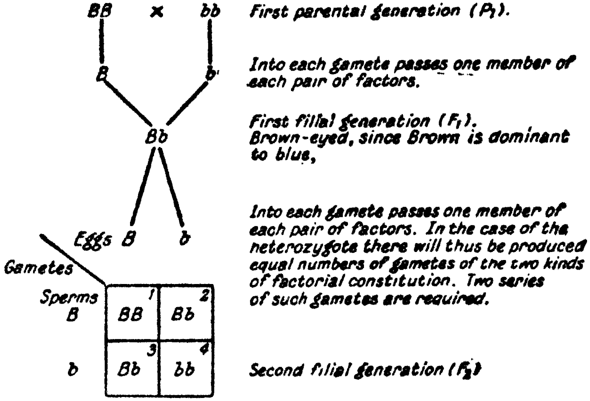
The law of segregation can be illustrated by the use of the human eye colour characters, brown and blue, if the following statements are accepted without question. Blue eyes mated to blue give only blues; brown eyes to brown give only browns, if the browns have had only a brown-eyed ancestry. If, however, brown eyes with an ancestry including blue eyes are mated with blue eyes, then it may be expected that among their offspring browns and blues will occur in more or less equal numbers. If brown eyes of a brown-eyed ancestry mates with blue eyes, then all the offspring will be brown-eyed. If two such brown-eyed individuals out of a brown by blue parentage mate, then their children will be brown and blue eyed in the proportions of 3 : 1.

Mendel, to explain identical results obtained from the breeding of the edible pea, put forward the following hypothesis. There are characters which are inherited. Corresponding to these characters there are determiners, hereditary factors, in the gametes which in their union give rise to the individual. Each gamete carries a factor for each and every heritable character that the future individual may exhibit, and thus the individual, arising in the union of two gametes, has a double set of factors, each gamete a single set. Characters can be classified as *alternative* (allelomorphic). Thus, eye-colour can be brown or blue. Allelomorphic characters are alternative characters of one and the same structure or function. A brown-eyed individual can have received the factor for this character from both parents, being *duplex* for the factor and *homozygous* for the character. On the other hand, this brown-eyed parent may have received one factor for the brown-eye character by way of one gamete, and one factor for the alternative character, blue, by way of the other. The individual will then be *simplex* for the factor for brown-eye (and, therefore, also for the factor for blue), and *heterozygous* for the character exhibited; he or she will be brown-eyed because, for reasons as yet unknown, brown eye is *dominant* to the *recessive* character blue eye. A blue-eyed individual is one that is *nulliplex* for the brown-eyed factor and *duplex* for the factor for the blue-eyed character. This must be so since the simplex condition of the brown factor is enough to produce the brown-eyed condition.

Since the gamete is constitutionally simplex and the individual necessarily duplex, it follows that into each gamete elaborated by an individual there must pass one or other of each pair of alternative factors in the hereditary constitution of the individual. In respect of such characters for which the individual is homozygous, all gametes will be factorially similar, but in respect of those for which the individual is heterozygous, there will be two sorts of gametes, one kind carrying the factor for the one character, the other that for its allelomorph, and the two kinds will be elaborated in equal numbers. If of the two characters concerned one is dominant and the other recessive, if in any fertilisation there are available equal numbers of ova carrying respectively one or other of the factors for two alternative characters, and if there are equal numbers of spermatozoa carrying respectively one or other of the same two factors, and if fertilisation is at random, then chance will yield on the average in every four three individuals exhibiting the dominant character of the pair and one exhibiting the recessive.

Using this hypothesis, the case of the mating brown eye and blue eye can be interpreted if the postulated factor for brown-eye colour be represented by B, and that for blue by b. A brown-eyed person, if homozygous, has the factorial constitution BB, if heterozygous, Bb; a blue-eyed must be bb.

It will be seen that the ratio of the different classes in the second filial generation is actually 1 : 2 : 1.

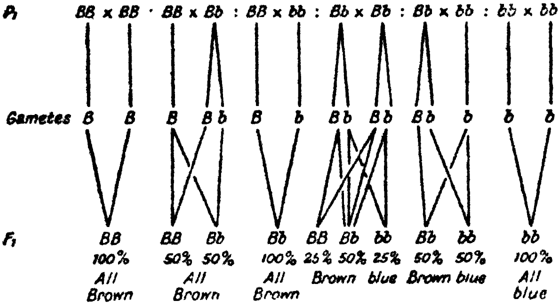

BB × bb
First parental generation (P_1).
B b
Into each gamete passes one member of each pair of factors.
Bb
First filial generation (F_1).
Brown-eyed, since Brown is dominant to blue,
Eggs B b
Gametes
Sperms
B
b
1 BB
2 Bb
3 Bb
4 bb
Into each gamete passes one member of each pair of factors. In the case of the heterozygote there will thus be produced equal numbers of gametes of the two kinds of factorial constitution. Two series of such gametes are required.
Second filial generation (F_2)

Character Classes.	*Factorial Classes.*	
B	BB	Homozygous Browns. Square 1. Total 1
Brown	Bb	Heterozygous Browns. Square 2, 3. Total 2
b blue	bb	blues (necessarily homozygous for this character, duplex for the factor b, and nulliplex for the factor B. Square 4. Total 1

Other matings within this blue-blue series also illustrate Mendel's first law quite clearly. The following matings are possible:

Homozygous Brown (BB) × Homozygous Brown (BB)
" " " × Heterozygous " (Bb)
" " " × blue (bb)
Heterozygous " (Bb) × Heterozygous Brown (Bb)
" " " × blue (bb)
blue (bb) × " "

The expected results of any of these can be predicted by the use of the chequerboard plan shown above.


P₁
BB x BB · BB x Bb : BB x bb : Bb x Bb : Bb x bb : bb x bb
Gametes
B B B B b B b B b B b B b b b b
F₁
BB BB Bb Bb BB Bb bb Bb bb bb
100% 50% 50% 100% 25% 50% 25% 50% 50% 100%
All Brown
All Brown
All Brown
Brown blue
Brown blue
All blue

A consideration of these expected results, which are confirmed by others extracted from critical observation, will show that the way in which homozygous and heterozygous browns may be distinguished most readily is that which involves their matings with blue-eyed persons. The homozygous brown-eyed individual mating with a blue-eyed will beget none but brown-eyed offspring: the heterozygous brown-eyed, on the other hand, may be expected, in such a mating, to produce both browns and blues. The hereditary constitution of an individual is revealed in the characterisations of the offspring and in the ratios exhibited by the different character groups among these.

It is now known that the phenomenon of dominance is an unessential feature of Mendelian inheritance. It is, in many instances, not exhibited, and the hybrid has a character which appears to be intermediate between those of the two parents; this type of inheritance is known as blending. What is essential is the orderly reappearance of the characters of the P_1

individuals, and of the F_1 individuals in the F_2 generation in definite numerical proportions.

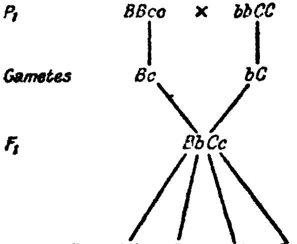
Mendel's second law, concerned with the independent association of factors, can be illustrated in a consideration of the facts relating to the synchronous inheritance of two pairs of allelomorphic characters. It has been shown that brown and blue eye-colours are a typical pair of Mendelian characters. Curly and straight hair constitute another similar pair, curly being dominant to straight, the mating curly and straight giving a 3 : 1 ratio in F_2.

It is found that if, for example, a homozygous brown-eyed, straight-haired individual mates with one who is blue-eyed, curly-haired (homozygous), the offspring are brown-eyed and curly-haired—*i.e.*, they exhibit the two dominant members of the two pairs of allelomorphic characters. The offspring of two such individuals, having similar family histories, will include, as is shown by data collected from many such families, on the average in every sixteen:

9 Brown-eyed and Curly-haired.
3 Brown-eyed and straight-haired.
3 blue-eyed and Curly-haired.
1 blue-eyed and straight-haired.

These facts can be explained by the scheme shown on p. 18. Let C represent the factor for the Curly condition of the hair, and c that for the alternative recessive straight.

In the F_2 generation it is seen that there are all possible combinations of the four characters in the experiment. There has been dissociation and recombination of the characters during the course of events between the F_1 and the F_2. The 9 : 3 : 3 : 1 ratio follows from the co-existence of two 3 : 1 ratios involved in a single mating.



A Brown-eyed straight-haired individual is mated with a blue-eyed Curly-haired

Into each gamete there passes one member of each pair of factors:

The F_1 individuals are doubly heterozygous, simplex for each of their factors.

Gametes / Sperm \ Eggs	BC	Bc	bC	bc
BC	1 BBCC	2 BBCc	3 BbCC	4 BbCc
Bc	5 BBCc	6 BBcc	7 BbCc	8 Bbcc
bC	9 BbCC	10 BbCc	11 bbCC	12 bbCc
bc	13 BbCc.	14 Bbcc	15 bbCc	16 bbcc

Into each gamete there passes one member of each pair. The distribution of the Bb pair is influenced in no way by that of the Cc pair, and so four kinds of gametes are elaborated.

Of these there will be two series, ova and sperm. If fertilisation is at random, there will be sixteen possible combinations and these will fall into four classes exhibiting the two dominants, one dominant, and one recessive, the other dominant and the other recessive, and the two recessives respectively; these classes will appear in the ratio 9 : 3 : 3 : 1.

Character Classes. (*Phenotypes*).	*Factorial Classes* (*Genotypes*).		
1. The two dominants, B and C ...	BBCC	1	
Brown Curly	BBCc	2	
	BbCC	2	
	BbCc	4	9
2. One dominant, B, one recessive, c	BBcc	1	
Brown straight	Bbcc	2	3
3. The other dominant, C, and other recessive, b	bbCC	1	
blue Curly	bbCc	2	3
4. The two recessives, b and c ...	bbcc	1	1
blue straight			16

The ratio in the F_2 of a trihybrid mating, a mating involving three pairs of allelomorphic characters, one member of each pair being dominant, is 27:9:9:9:3:3:3:1. It is possible to estimate the ratios for the F_2 of experiments involving four or more pairs of characters, but to obtain such ratios is usually impracticable in the case of animals.

Mendelism thus postulates the existence of a number of individual particles of substance—the so-called factors—in the germ-plasm, each of these in its action influencing the development of some particular character. It does not require that these factors shall be concerned solely with hereditary transmission, but demands that in respect of any particular hereditary character the individual must receive from its parents, one from each by way of the gametes, two factors either similar or dissimilar, according to whether or not in respect of this particular character the parents are alike or different. It requires that when the individual in its turn elaborates gametes, into each there shall pass one or other, but not both of these factors. The gamete can contain, therefore, only a single set of factors. The fertilised egg and the body cells of the individual, on the other hand, contain a double set, and of these one has been received from each parent.

Thus it is, according to this theory, that the individual can be hybrid, "impure," in respect of a character or characters, since one or more pairs of factors in its hereditary constitution can consist of dissimilar mates. The gamete, on the other hand, cannot be hybrid, it must be "pure," since of each pair of factors it can contain but one member. The theory postulates that the association of dissimilar factors in the cell is not attended by any adulteration effect upon them.

It may make the matter simpler if one compares the chromosomes to playing cards. Each individual would then possess a hereditary constitution which would be equivalent to two complete packs of cards, the packs being different in having differently coloured backs, one red, one blue, let us say. The reduction phenomena at the time of production of the ripe gametes ensure that this double pack is sorted out into two single packs again, but pay no attention whatsoever to the colour of the backs of the cards. Each pack when sorted out will be complete in having one card of each kind, but any of the cards may have either a red or else a blue back. Thus it would be most unlikely that in the matter of the colour of the backs any one of the sorted out packs will be identical with any other, since the number of possible combinations is so very large.

Of the two ten of diamonds cards, one has a red back, the other a blue. Into each ripe gamete there will pass one or the other ten of diamonds and the distribution of these two cards has no effect whatsoever upon the distribution of, let us say, the two sixes of spades. One may get a red-backed heart with a red-backed spade or with a blue-backed spade, or a blue-backed heart with a blue-backed spade or a red-backed spade. It is this independent segregation of the different pairs of factors that makes the genetical method of breeding of practical as well as of theoretical importance, for it enables the student to take the hereditary constitution to pieces and to put it together again in new ways. One can, by appropriate matings, collect in one and the same hereditary constitution all the useful characters that are to be found scattered through a number of different strains or races.

The Mendelian method of character analysis, ardently pursued during the first decade of the twentieth century, made it perfectly clear that, if there was a material basis of organic inheritance, if this germ-plasm did exist, in fact, then in the cell there must be some unit which is structurally continuous through all cell-division from the first cleavage of the fertilised egg to the elaboration of the ripe gametes of the resulting individual, that these units must be present in duplicate and in pairs in the fertilised egg, and that they must segregate into single components at some point before the ripe gametes are formed.

As was to be expected, it was not long before results were obtained from breeding experimentation which demanded some extension and modification of the theory as originally promulgated by Mendel, but though the original factorial theory of organic inheritance has become somewhat refined, essentially it remains unaltered.

CHAPTER II

THE ARCHITECTURE OF THE GERM-PLASM

This modification of the original Mendelian theory was made necessary by developments in knowledge concerning the minute anatomy of the living cell. It became more and more certain that of all the organs of the cell, the chromosomes alone, because they most nearly satisfied the demands made upon the distributive mechanism of organic inheritance by the facts of critical experimental breeding work, could be the germ-plasm. It became recognised that the exact parallelism between the distribution of hereditary characters among the generations and the distribution of the chromosomes from mother cell to daughter cells afforded an entirely satisfactory explanation of the ratios obtained in Mendelian hybridisation work, if it is assumed that the factors of Mendel are resident in, or are borne upon, the chromosomes, for the factor will go whither the chromosome passes so long as the latter retains its integrity.

The modern chromosome theory relating to the distributive mechanism of inheritance postulates that the hereditary factors are resident in, are borne upon, the chromosomes, that upon each chromosome is borne a certain association of factors, and that each factor has its own peculiar place upon a particular chromosome. It follows that those characters whose factors are resident in one and the same chromosome will not show free assortment but will be inherited together, remaining linked in their transmission from generation to generation, unless these factors become separated through a fracture of the chromosome that bears them.

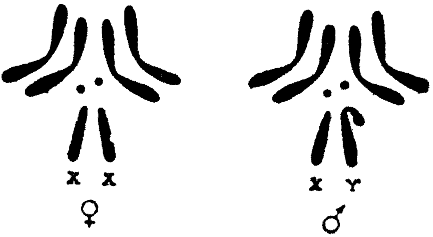


FIG. I.—CONVENTIONAL DIAGRAM OF THE CHROMOSOMES OF "DROSOPHILA MELANOGASTER."

For examples that clearly illustrate the parallelism which exists between the distribution of the hereditary transmission and that of the chromosomes, it is desirable to turn to the fruit-fly, *Drosophila melano-*

gaster, in the body cells and immature gametes of which there are but four pairs of homologous chromosomes, the members of any one pair being identical in size and shape (with the exception about to be stated). In the ripe gamete, egg or sperm, there are four single chromosomes, and because the chromosomes of the different homologous pairs differ one from the other in their size, shape, and relative position, it can be demonstrated that in the ripe gamete there is present one member of each pair, and that in the fertilised egg the diploid (double) number is restored and that of each reconstructed pair one member has been brought into the zygote by the sperm, the other by the egg. In respect of its chromosomes, the new individual receives from each of its parents one member of each homologous pair.

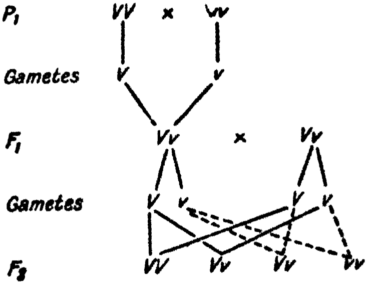
The chromosome picture differs in the two sexes. In the tissues of the female the members of each pair of chromosomes are identical. In the case of the male tissues one member of one pair is exactly similar in form, size, and disposition to the two members of the corresponding pair in the female, but its mate is unequal, is dissimilar. Since in respect of this pair the sexes differ, these chromosomes in the two sexes are referred to as the sex-chromosomes. The three chromosomes that are alike, two in the female and one in the male, are referred to, for descriptive purposes, as the X-chromosomes; the unequal mate of the X in the male is known as the Y-chromosome. Since of each pair of chromosomes only one can be present in the ripe gamete, then in respect of the sex-chromosomes all eggs must be alike, each containing an X, whereas there will be two sorts of sperm, the X-chromosome-bearing and the Y-chromosome-bearing. If an X-bearing egg is fertilised by a Y-bearing sperm, an XX-bearing zygote will result. The XX type of chromosome content is the female. If an X-bearing egg is fertilised by a Y-bearing sperm, an XY type of individual will result, and this constitution is typical of the male.

With this knowledge concerning chromosome constitution and distribution in Drosophila, it is now possible to examine the observed results of experimental breeding and thereafter to demonstrate how these results are to be interpreted in terms of the chromosome hypothesis.

1. If as a parental generation (P_1) a fly with the wild type "long" wings is mated to one with short and useless wings (this character, "vestigial wing form," appeared as a sport or *mutation* in a long-winged stock), the first filial generation (F_1) are all long-winged. The character "long-winged" is dominant, and in relation to it vestigial is recessive. If these F_1 long-winged flies are interbred, they will produce a second filial generation (F_2) which includes two classes of flies in respect of wing form—long-winged and vestigial—and in every four on the average there will be three of the former to one of the latter.

The 3 : 1 ratio in the F_2 of an experiment such as this can be explained if the following assumptions are made: The chromosomes are the germ-plasm. In them are resident the factors or *genes* which, in their action, determine the future characterisation of the individual, controlling the differentiation of the organs and tissues during development. There is a factor for long-winged and another factor for vestigial, but only one of these can be present at any time in the particular chromosome that carries them. In each of the chromosomes of a particular pair in the long-winged race there is a factor (V) corresponding to the character long-winged; in the case of the vestigial race there is instead a factor for vestigial (v). In respect of the factorial content of the remaining chromatin, the two parental forms are regarded as being identical. Of this particular pair of chromosomes, the F_1 individual will have received one from each parent; one will carry the factor for long-winged, the other that for vestigial. The observed fact is that long-winged is dominant and vestigial recessive. When these F_1 individuals elaborate their gametes, into each passes either the chromosome bearing the factor for long-winged or else the chromosome bearing the factor for vestigial. If there are equal numbers of the two sorts of eggs and equal numbers of the two sorts of sperms, and if fertilisation is at random, the following chromosome associations will result, and the four sorts will be equally frequent: long-winged: long-winged; long-winged: vestigial; vestigial: long-winged; and vestigial: vestigial. Since the character long-winged is dominant to vestigial, there will be on the average in every four, three long-winged flies to each vestigial in F_2.

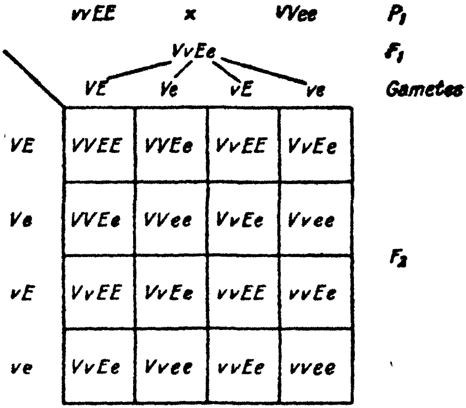
These results can be illustrated in simple fashion if each letter V or v is accepted as representing a chromosome, one of the large boomerang-shaped ones. In this experiment one pair of homologous chromosomes is involved.



The mechanism of the distribution of the chromosomes during cell division is one which can provide for the transmission of the hereditary characters, if upon the chromosomes are resident the hereditary factors or genes. The gene within the chromosome must necessarily go whither the chromosome passes.

2. If a vestigial-winged fly, with the wild-type body coloration grey, is mated with a long-winged, ebony-coloured fly (the ebony coloration appeared as a mutation in a grey stock), the F_1 flies will be long-winged greys (grey is dominant to ebony). They will exhibit the two dominant members of the two contrasted pairs of characters. If these F_1 flies are interbred, they will produce four classes of offspring in F_2 —long-winged greys, long-winged ebonies, vestigial greys, and vestigial ebonies—and in every sixteen on the average these four classes will appear in the relative proportions of 9 : 3 : 3 : 1. It is to be noted that the two characters of respective parents, vestigial grey and long-winged ebony, have become dissociated and recombined.

The 9 : 3 : 3 : 1 ratio can be explained if it is assumed that the factors for the body colour characters, grey (E) and ebony (e), are not resident in the same chromosome pair as are those for vestigial (v) and long-winged (V). Two different pairs of chromosomes (V and v, E and e bearing) are concerned. The remaining chromatin in both parental forms is to be regarded as identical. The factorial constitution of the P_1 individuals will be vvEE and VVee respectively; that of the F_1 individuals VvEe, and these later will elaborate four sorts of gametes in equal numbers, VE, Ve, vE, and ve. The union of two series of such gametes must yield on the average in every sixteen, nine fertilised eggs with both V and E (these must be long-winged greys), three with V but not E (long-winged ebonies), three with E but not V (vestigial greys), and one with neither V nor E (vestigial ebonies). The results can be illustrated if, as before, each letter is accepted as representing a chromosome. Two pairs of homologous chromosomes are concerned—the two pairs of large boomerang-shaped ones. Each member of the one pair carries either the factor V or v; each of the other pair either the factor E or e.



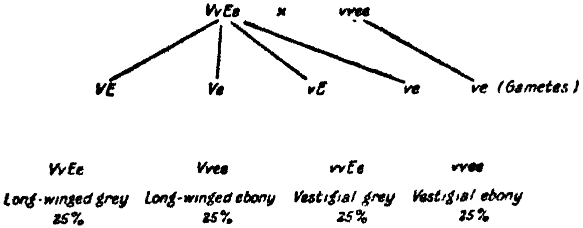
	VE	Ve	vE	ve
VE	VVEE	VVEe	VvEE	VvEe
Ve	VVEe	VVee	VvEe	Vvee
vE	VvEE	VvEe	vvEE	vvEe
ve	VvEe	Vvee	vvEe	vvee

Any fertilised egg with the factors—

V and E will be long-winged grey ...	9
V but not E will be long-winged ebony	3
E but not v will be vestigial grey ...	3
Without E and V will be vestigial ebony	1

3. If a long-winged grey F_1 male out of the mating vestigial grey and long-winged ebony is mated with a vestigial ebony female, there will be produced *four classes of offspring in equal numbers*—long-winged greys, long-winged ebonies, vestigial greys, and vestigial ebonies. These results can be explained just as simply. The sperms of the male will be of four sorts (as above), and they will be produced in equal numbers. All the gametes of the female will be alike in respect of the genes for vestigial and ebony. It follows, then, that since vestigial and ebony are recessive characters, the number and proportion of the

classes in the resulting generation are predetermined by the number and proportion of the different sorts of sperms elaborated by the male. These will be as before—VE, Ve vE, and ve. These fertilising ve eggs must yield long-winged greys (VvEe), long-winged ebonies (Vvee), vestigial greys (vvEe), and vestigial ebonies (vvee) in equal numbers.



It will be recognised that so long as there are as many chromosomes as there are independently heritable characters, there is no difficulty in accounting for the free assortment and recombination shown in the transmission of these characters, as will be seen from the following table:

No. of Chromosomes in the Gamete (the Haploid Number).	*No. of possible Combinations of Maternal and Paternal Chromosomes in the Fertilised Egg.*
1	4
2	16
3	56
4	256
5	1,024
6	4,096
7	16,384
8	65,536
9	262,144
10	1,048,576

There are twenty-four chromosomes in the gamete of man, so that it can be seen that infinite variety of combinations in the fertilised egg is possible, even although each chromosome bears but a single hereditary factor.

In Drosophila there are many hundreds of characters that can be paired off in the same way as vestigial and long-winged, grey body colour and ebony, yet in each gamete there are but four chromosomes to bear their factors. It follows that either the chromosome hypothesis fails to satisfy the demands made upon it, or else more than one factor is resident in one and the same chromosome. If the factors for several different characters are resident in one and the same chromosome, then if that chromosome preserves its integrity during its transference from cell to cell, the characters corresponding to the factors resident therein should be transmitted together and should remain *linked* in inheritance.

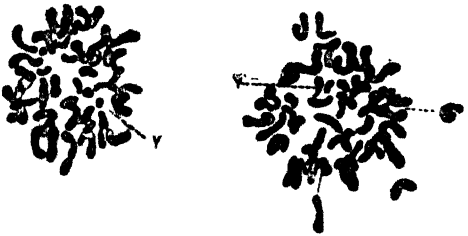


FIG. 2.—THE CHROMOSOMES OF MAN. (*After Painter.*)

As an example of linkage the following case can be cited:

4. If a vestigial black fly (not ebony, but another body colour character very similar on inspection) is mated with a long-winged grey, all the individuals of the F$_1$ generation will exhibit the two dominant char-

acters—long-winged and grey. If a male of this generation is mated to a vestigial black female—*i.e.*, one exhibiting the two recessive characters, *only two classes of offspring* will appear—vestigial blacks and long-winged greys—and these will be produced in equal numbers. (Compare the results of this back-crossing in 3, page 28.) It will be noticed that the character associations in this generation are exactly those that were exhibited by the two flies with which the experiment started. If the factors for black and vestigial are resident in one and the same chromosome, then these results can be interpreted. Each pair of brackets, ( ), represents a chromosome, and the letters within represent factors resident upon that particular chromosome.

Grey Long-winged   black vestigial
P_1 (BV) (BV) × (bv) (bv)
F_1 ♂ (BV) (bv) × (bv) (bv) double recessive ♀
(BV) (bv)   (bv) (bv)
Grey   black
Long-winged   vestigial
50 per cent.   50 per cent.

It has been found that all the characters so far examined in Drosophila fall into four groups. The members of any one group give among themselves this 50 per cent. : 50 per cent. ratio when any pair of them are involved in a breeding test similar to that above, but when any one of them is associated with a member of any other group, the result is a 25 : 25 : 25 : 25 ratio, similar to that in the vestigial-ebony experiment described in 3 (page 27). There are four linkage groups and four chromosomes. It is reasonable to argue that upon a particular chromosome are resident the genes of a particular group of characters. More will be said of this conception later.

It has been found by experimental breeding that in each species there is a certain number of character linkage groups, and it has been shown that this number is the same as that of the chromosomes in the gamete. The members of the different character linkage groups assort independently in accordance with Mendel's second law, while the numbers of one and the same linkage group, on the other hand, remain linked in inheritance.

5. If instead of the F_1 male (as in 4) an F_1 long-winged grey *female* is mated to a vestigial black male, then four classes of offspring will be produced, not two as in 4, and not in equal numbers as in 3, but in the following relative proportions: long-winged greys, 41·5 per cent.; vestigial blacks, 41·5 per cent.; long-winged blacks, 8·5 per cent.; and vestigial greys, 8·5 per cent. It is to be noted that this result differs from that in 4 in that there is a dissociation and recombination of characters, but only to a certain limited extent. It is seen that the 50:50 ratio is not obtained when an F_1 *female* is mated with the double recessive.

It will be agreed that the reason for the production of four classes of offspring instead of two must be that the F_1 female elaborated four sorts of egg instead of two, for the sperm of the double recessive male are all alike, each carrying the factors for vestigial and black, and since these characters are recessive, they will not disguise the results. The classes and the proportions of these can be explained if the F_1 female elaborates the following kinds of eggs in the proportions suggested:

(BV) 41·5 per cent.:(bv) 41·5 per cent.:
(Bv) 8·5 per cent.: (bV) 8·5 per cent.

In order that these four sorts shall be elaborated in these proportions, it is necessary that in the maturation of 17 per cent. of the eggs there shall be an interchange of chromatin between the chromosomes B-V and b-v in such a way that the part of the one chromosome carrying the gene B shall be detached from the rest carrying V; that the parts of the other chromosome shall be similarly separated; and that these chromosomes shall then reunite in such a way that part of one unites with part of the other. It will be noted that interchange leads to significant results only when the chromosomes concerned are dissimilar in their genetic constitution. It is in the case of the " heterozygous " females that such interexchange leads to the production of recombination classes. For reasons at present unknown, crossing-over does not occur in the case of the male of Drosophila.

The two new combinations after the interchange has taken place show again the same linkage relations to each other as did the former associations, showing that the linkage relation is independent of the characters that form the combination. Linkage between black and vestigial is exactly similar to that between grey and vestigial, and between black and long-winged. Such an interchange of chromatin between the two members of a pair of homologous chromosomes is known as crossing-over, and the percentage of the recombination or cross-over classes is referred to as the crossing-over value (C.O.V.), whilst the linkage between two genes is expressed by the percentage of cases in which they remain together. If the linkage in a particular case is 50 per cent., and the C.O.V. is 50 per cent., the result would exactly simulate the effects of free assortment, giving a 25 : 25 : 25 : 25 per cent. ratio. As a matter of fact, this situation has not arisen in the case of Drosophila, being prevented by the occurrence of double crossing-over—fracture and reunion at two points in the chromosome some distance one from the other.

During the maturation divisions in the production of the gametes, the segregation of homologous chromosomes is complicated by the fact that the members of each pair, prior to their separation, become most intimately intertwined. This apparently single, but really double, chromosome then splits longitudinally. This conjugation of homologous chromosomes provides the opportunity for crossing-over. It cannot be shown to have occurred, but if during this conjugation the two chromosomes stick, fracture, and rejoin before separation, then interchange of chromatin will have occurred, and the frequency of such interchange furnishes evidence of the linear order of the hereditary factors with respect one to another. The equivalent chromosome contributions of the two parents and their random assortment in maturation and chance recombination in fertilisation, together with this possibility of an inner reorganisation of each chromosome through its most intimate association with another of identical structure but different content, provide an infinite range of new combinations of characters which will give pleasing diversity to the species and will provide the raw material which can be tested out by environmental agencies. The chromosome mechanism can supply the variations upon which the forces of selection can operate. It becomes apparent also that this conjugation of chromosomes excludes the possibility of fruitful crosses between species widely different in chromosome constitution.

If the conjugation of homologous chromosomes is accepted as evidence in support of the conception of crossing-over, and if the factors are strung like beads upon a string, each particular factor having its own particular locus upon a particular chromosome, then it follows that the percentage of crossing-over between any two loci can be regarded as an indication of the distance between them. If the members of a pair of homologous chromosomes during their conjugation are as likely to fracture and reunite at one point as at any other point along their length, it follows that the further apart any two factors lie in the chromosome, the greater is the chance of crossing-over occurring. If this is so, then it is possible to construct a map of the chromosomes, showing the relative positions of the different factors resident in each. If A, B, and C form a linear series, and if B lies between A and C, then the crossing-over percentage occurring between A and C should equal the sum of the crossing-over values between A and B, B and C. The conception of the localisation of the hereditary factors in linear alignment is due to the peculiar differences between the crossing-over value between factors of the same character linkage group. The relation of three or more points to each other is a relation of linear order, and cannot be represented in space in any other manner than by a series of points arranged in a line. Linearity is the expression of a system in which there is a fixed succession of elements. The distance between any two elements is constant, but is variable throughout the series. In the case of the more simply organised forms of life, it is possible to conceive the germ-plasm having the form of a congeries of chromatin units, the members of which can exist separately within the nucleus and become associated by chance. In the more complex forms, however, the precision exhibited in the inheritance of a most complicated characterisation demands a very precise and more complex hereditary mechanism, such as is supplied by the chromosomes in their constitution and behaviour.

THE CHROMOSOME MAP OF DROSOPHILAMELANOGASTER.

Chromosome I.

0·0	Yellow
1·5	White
5·5	Echinus
7·5	Ruby
14·0	Crossveinless
20·0	Cut
27·5	Tan
33·0	Vermilion
36·0	Miniature
44·5	Garnet
56·5	Forked
57·0	Bar
65·0	Cleft
70·0	Bobbed

Chromosome II.

0·0	Star	52·5	Purple
4·0	Expanded	65·0	Vestigial
9·0	Truncate	70·0	Lobe
14·0	Streak	73·5	Curved
22·0	Cream B	85·0	Minute
29·0	Dachs	88·0	Humpy
33·0	Ski II	98·5	Plexus
46·5	Black	103·0	Brown
51·0	Cinniabar	105·0	Speck

Chromosome III.

0·0	Roughoid	52·0	Warped
10·0	Star-intensifier	54·0	Spineless
15·0	Smudge	54·5	Bithorax
20·0	Dwarfoid	58·3	Two-bristles
25·0	Benign III	59·0	Glass
25·5	Sepia	62·0	Stripe
26·0	Hairy	63·5	Delta
32·0	Divergent	65·5	Hairless
34·0	Cream III	67·5	Ebony
38·5	Dichaete	70·7	Sooty
39·1	Lethal III F	72·0	White ocelli
40·2	Tilt	75·7	Cardinal
42·0	Scarlet	83·0	Lethal III A
43·5	Ascute	86·5	Rough
45·0	Pink	90·0	Pointed wing
46·0	Curled	93·8	Beaded
46·5	Smudge	95·5	Claret
47·5	Deformed	101·0	Minute 23
48·0	Peach	106·2	Minute G
51·0	Dwarf		

Chromosome IV.

0·0	Bent
1·0	Eyeless

In the making of this chromosome map, 1 per cent. of crossing-over is taken as the unit for expressing linkage relations. This unit can be represented in a diagrammatic map of the chromosomes as 1 cm. or any other convenient size. A line is drawn to represent a chromosome. A horizontal mark across it is made to represent the position of the factor for dachs, for example. Twenty-two units of distance to one side of it, another mark is made for the factor for cinnibar, and twenty units to the other side of it, the mark for the factor for truncate is made, these figures being the crossing-over values between dachs and cinnibar and between dachs and truncate. The making of the map is begun. Some 107 factors require to be placed in this chromosome. Their characters all show linkage with dachs and cinnibar and truncate, and with each other, and the C.O.V. between any two of them is characteristic. Out of crossing-over work with them it is soon possible to arrange them all in their proper order. In the other linkage groups of Drosophila there are some 70, 106, and 3 characters respectively. All that remains is to show which particular chromosomes carry the genes for a certain character linkage group.

6. If a white-eyed male is mated to a (wild type) red-eyed female, all the F_1 are red-eyed, and these individuals being interbred, the F_2 will consist of three reds to one white in every four on the average (see p. 24), *but all the white-eyed individuals will be males.* The recessive character of a grandfather is exhibited by none of his children, by none of his granddaughters, and by only 50 per cent. of his grandsons.

P_1 (wX)Y × (WX)(WX)
F_1 (WX)(wX) : (WX)Y
F_2 (WX)(WX) : (WX)Y : (WX)(wX) : (wX)Y

7. If, on the other hand, a red-eyed male is mated to a white-eyed female, then all the males of F_1 will exhibit the white-eye character of their mother, whereas all the F_1 females will exhibit the red-eye character of their father.

P_1 (WX)Y × (wX) (wX)
F_1 (WX) (wX) : (wX)Y
F_2 (WX)(wX) : (WX)Y : (wx)(wX) : (wX)Y

A consideration of the facts related in 6 and 7 will lead to the conclusion that the characters red and white-eye are being transmitted from generation to generation by some mechanism which is also concerned in the determination of the sex of an individual, and that the simplest interpretation of the facts can be made if it is assumed that the male, in respect of the elements of the sex-determining mechanism, elaborates two sorts of sperm, one, the X-chromosome-bearing, the other, the Y-chromosome-bearing, and, if it is assumed further that in the X-chromosome are resident the factors for those characters which in their inheritance behave as does white-eye, being sex-linked, and that in the Y-chromosome there are no factors.

It can be accepted that the X-chromosome (Chromosome I) bears the factors of the sex-linked group of characters. It can be shown that the small, round, centrally placed chromosome (Chromosome IV) carries the factors for another group of linked characters. Individuals with but a single IV-chromosome (Haplo-IV's) and others with three instead of two (Triplo-IV's) have been identified, and these abnormalities in chromosome number revealed by the microscope are associated with definite abnormalities in general superficial characterisation. On Chromosome II, one of the larger boomerang-shaped chromosomes, are placed the factors of the characters linked with the character black, on the other large curved chromosome (Chromosome III), those linked with the character Star.

This modern theory of organic inheritance, like its forbears, is a particulate theory, implying that the germ-plasm of organisms is not an indivisible whole, but an organisation of units or factors which may be dissociated and recombined in various ways. It is held that the hereditary constitution of an individual is not only composed of units in particular proportions and arrangement, but that its effects are determined by these proportions and arrangement just as much as by the particular nature of the elements themselves.

It remains to state how, according to this theory, new characters arise, how new hereditary factors have their origin. A factor is regarded as a particular state of the chromatin at a particular point along the length of a particular chromosome, the chromosome, so to speak, as a convenient length of the hereditary material, the germ-plasm. This particular state or organisation of the chromatin at this particular point can give place to others, and with each change a new factor appears. Such a change is an instance of "sporting," of point mutation.

Since the hereditary characters are based upon these factors, it follows that our knowledge of the hereditary constitution of any particular form is limited by the frequency of mutation in that form. Observation indicates that mutation is rare, that the factor is stable, resisting most efforts to change it. The student of heredity, therefore, has had to wait for mutation to occur, and thus for new characters to make their appearance, for thus far he has not been able to command mutation. Thus it is that so little is known concerning the hereditary constitution of most forms, particularly those of the larger animals, including man. Our knowledge of the hereditary constitution of any form of living things will increase abundantly when methods of increasing the frequency of mutation at will have been discovered and refined.

CHAPTER III

HEREDITY AND SEX

In the great majority of animals every individual is either a male or else a female, and the sexes are to be distinguished one from the other by differences in skeletal, cutaneous, functional, and mental qualities, for example, in the size of the body generally or in that of local parts, in the structure and colour of the plumage in birds, in the distribution of hair in man and mammals, in the pitch of the voice, in the number of the red blood corpuscles per unit volume of blood, in the chemical properties of the body fluids.

In the higher forms the sexes are to be distinguished by differences in the form and function of the different organs of the reproductive system. In the lower forms of life the gametes, the products of the sex-glands, are merely liberated at the body surface, and the chances of the fertilisation of the ova by the sperm are relatively remote, but in the higher forms, in addition to attractive structures and behaviour which bring the sexes together for mating, there are wonderful contraptions which make the union of sperm and ovum practically certain. The gonads, the sex-glands themselves, differ in the two sexes; the female has ovaries, the male testes, the former elaborating ova, the latter sperm. In both sexes there are ducts which convey the gametes towards the site of fertilisation, and the architecture of these ducts is different in the two sexes. The external organs of reproduction are also sexually distinct, those of the male being in their form complementary to those of the female, and the two together forming an efficient equipment for fruitful sexual congress.

Finally, the sexes are to be distinguished by constant and characteristic differences in the chromosome content of their cells. There is a sex-chromosome sex-determining mechanism which operates at the time of the fertilisation of the egg by the sperm. In man and mammals the male elaborates two kinds of sperm in respect of the elements of this sex-determining mechanism, one kind, which fertilising any egg, gives rise to a male, the other, fertilising any egg, yields a female, whereas the female produces eggs all of a kind so far as the elements of this sex-determining mechanism is concerned. This mechanism yields results which are in every way comparable to those that are obtained when a heterozygous dominant (Aa) is mated to a recessive (aa) in a typical Mendelian experiment, equal numbers of the two classes that are represented in the mating. In respect of the factors that are borne on the X-chromosome, the male is constitutionally simplex since he has but one of these chromosomes, the female, on the other hand, may be duplex, since she has two; so it is that the results of reciprocal matings in which sex-linked characters are involved, are different. In the case of the fowl and birds generally, it is the female that elaborates two kinds of eggs in respect of the elements of the sex-determining mechanism, the male that produces but one kind of sperm. The observed facts of sex-linked inheritance, the term used to describe that mode of hereditary transmission of characters which can only be explained on the assumption that the mechanism which is responsible for the distribution of the hereditary characters is the same as that which is responsible for the determination of sex, all point to the conclusion that sex is determined at the time of the fertilisation by the sex-chromosome distributing mechanism.

As an example of sex-linked inheritance, the condition of hæmophilia can be cited. A hæmophilic is a "bleeder," an individual whose blood does not clot. It is highly dangerous, therefore, for such individuals to have teeth extracted or to cut themselves. A review of family histories reveals the facts that a man can be either hæmophilic or normal, and that a female can be hæmophilic, normal, or else a carrier—*i.e.*, non-hæmophilic herself, but carrying the factor for this condition and transmitting it to her children. The following table presents the facts concerning the transmission of this character:

Hæmophilic man	×	hæmophilic woman	= sons and daughters all hæmophilic.
„	×	carrier woman	= sons either hæmophilics or normals; daughters either hæmophilics or carriers.
„	×	normal woman	= sons normals, daughters carriers.
Normal man	×	hæmophilic woman	= sons hæmophilics, daughters carriers.
„	×	carrier woman	= sons hæmophilics or normals; daughters carriers or normals.

These facts can only be explained on the assumptions that the factor for this hereditary character is borne upon the X-chromosome; that the male has but one X-chromosome, the female two; that in an XX-individual, a female, the factor on the one X can be balanced by the factor for the alternative character "normality" on the other; and that sex is determined at the time of fertilisation, there being " male-determining " and " female-determining " spermatozoa.

This conclusion is confirmed by the facts concerning the chromosome constitutions of the sexes and of the gametes. It is further confirmed by the facts of a peculiar kind of intersexuality known as gynandromorphism. In Drosophila, for example, lateral gynandromorphs are relatively common, the characterisation of an individual being entirely and completely female in one half of the body, completely male in the other. If the tissues of the male portion are examined microscopically, it is found that in the cells there is one instead of two sex-chromosomes, whereas in the female portion the cells have the normal number, two. This condition is due to the elimination of one of the X-chromosomes of a fertilised egg, XX in sex-chromosome constitution during the early divisions, whereby one of the daughter cells of a dividing cell fails to receive one of the daughter X-chromosomes. The result is that all cells having their origin in this X-chromosome-deficient cell will have the chromosome constitution of the male (it being assumed that in this form the factors in the Y-chromosome of the normal male play no part in sex-determination), whereas all the cells and tissues that are derived from the cell which receives two daughter X-chromosomes will have the normal female sex-chromosome constitution.

A consideration of these facts leads to the conviction that sex-determination primarily and fundamentally is an affair of the hereditary constitution of the individual. In Drosophila and man, for example, an individual is a male because the fertilised egg in which he had his beginning had one X-chromosome associated with two of each of the other chromosomes (1X : 2A), whereas a female is a female initially because the fertilised egg in which she had her beginning had two X-chromosomes associated with two of each of the other chromosomes (2X : 2A or 1X : 1A).

It is reasonable to assume that this sexual difference in the hereditary constitution is reflected in a corresponding difference in the physiological qualities of the two kinds of fertilised egg—the "determined" male and female respectively. If the hereditary factors elaborate substances of a chemical nature, then the internal environment of the "male" fertilised egg can be significantly different from that of the "female" fertilised egg. In one there will be an environment of "maleness," in the other an environment of "femaleness," and in these environments the processes of development proceed. The rudimentary gonads in the female become ovaries because they develop in a female; in the male they become testes.

There is no difficulty in demonstrating that, when once they are developed, these sex-glands play an all-important rôle in the establishment and maintenance of the observable sexual differences. That this is so is illustrated in the following aphorisms, which in their sequence show the historical development of the modern point of view: "*Propter solum uterum mulier est, quod est*"; "*Propter solum ovarium mulier est, quod est*"; "*Propter secretiones internas totas mulier est.*"

There is no difficulty in demonstrating that the functional activity of the ovary and testis is a condition of the normal development and maintenance of such of the sex-distinguishing characters as are secondary gonadic, since by definition these are such as are dependent upon the gonad. The criterion of a secondary gonadic character is that it reacts to the physiological activity of the gonad in a particularly definite way. It is established that the gonadic influence punctuates the growth of the long bones, thereby affecting the general proportions of the body; that it influences the development and the functioning of the central nervous system and affects the processes of general metabolism. But in addition, and especially, the physiological activity of the gonads exerts a strong and definite influence on certain structures and functions which constitute the commonly and readily recognised sex-dimorphic characters.

The intimate and significant relation between gonad and secondary gonadic characters is revealed by the results of (1) gonadectomy (the surgical removal of the sex-glands), (2) gonad implantation, and (3) administration of prepared products of the gonads.

(1) *Gonadectomy.*—Castration of the new-born male rat is followed by a non-development of the reproductive organs, but has no effect upon general development. Since there is a sex-dimorphic difference in growth rate, and since removal of the testes does not affect general development, it would seem that growth rate is dependent upon sexuality, but that it is not a secondary gonadic character. In the case of the female, the ovary apparently does not exert any influence upon the body generally before the time of attainment of sexual maturity. This can be demonstrated by injecting ovarian extract or by implanting adult ovary into the immature female, when rapid growth and differentiation of the genital organs ensue, though only in cases in which these have already attained a certain stage of growth.

The effect of castration varies according to the age at which the operation is performed. Following removal of the testes before sexual maturity (later than in the case of the new-born), the genital organs do not develop normally; the penis and its ducts and glands remain incompletely developed and of small size. In man the beard does not grow until, in old age, the castrate develops one similar to that of the aged female; the hair in the *regio pubis* has a horizontal base line, as in the female, whilst the chest, axillæ, and the extremities remain hairless. The localisation of subcutaneous fat is characteristic, much accumulating on the buttocks, under the breast, on the *mons veneris*, and on the lateral aspects of the upper eyelids. The region of active growth at the ends of the long bones persists even to the age of thirty-five, so that the castrate attains a relatively greater height with disproportion of the body. The pelvis remains infantile, as does the larynx. Erection and cohabitation remain possible for a considerable time in some cases. The general intelligence is not obviously affected, but general apathy is characteristic.

Castration after puberty is followed by a non-development or a disappearance of the beard and a change in the regional distribution of the body hair, and a localised disposition of subcutaneous fat. The larynx becomes small and the voice high-pitched. Sexual libido may persist for some time, but ultimately disappears.

Surgical removal of the ovary in the human is performed only in cases of disease and late in life, and the sequelæ are therefore not well marked. Atrophy of the reproductive organs takes place, especially of the vagina and the womb. A marked accumulation of fat and an increase in body weight occur. Generally there is a decrease in the size of the breasts and in sexual libido. In some cases ill-defined mental disturbances follow.

The evidence derived from the results of removal of the sex-glands points to the conclusion that the development and maintenance of many structural, physiological, and psychical characters are dependent upon the integrity and functional activity of the gonads. The gonads affect not only the components of the accessory sexual apparatus—the ducts and glands associated with the gonads—but also such sex-dimorphic characters as the regional distribution of the hair and the pitch of the voice. Metabolism is significantly reduced, that of fats particularly, that of carbohydrates less so, and that of proteins not at all. Following gonadectomy, the neat interrelationship of the members of the endocrine chain (thyroid, pituitary, adrenals, etc.) is disturbed, and certain of the effects of gonadectomy may be but secondary to the indirect effects of this operation upon some other member or members of this system of ductless glands. It is seen that the effects of gonadectomy upon the sex-dimorphic characters vary according to the time at which the operation is performed in relation to the time of attainment of sexual maturity, prepubertal gonadectomy resulting in non-development of the genital organs and secondary gonadic characters, whilst the effect of post-pubertal gonadectomy is in inverse ratio to the age of the individual at the time of operation.

2. *Gonad Implantation.*—It is recognised that removal of the gonads is followed by a definite train of events, and it is reasonable to assume that the phenomena which follows extirpation of the gonads are caused thereby. If this is so, then it may be assumed that the successful and timely implantation of appropriate gonadic tissues should result in the restoration of normal sexuality in the case of the gonadless individual, and implantation generally should be followed by phenomena which can be regarded as the effects of this procedure.

There is no difficulty in demonstrating that complete maleness and femaleness cannot be assumed and cannot be maintained in the absence of normally functioning glands other than the gonads, but these glands of internal secretion, such as the thyroid, stand in a different relationship to sexuality from that which the gonad occupies. Extirpation or disease of any of these in the mammal leads to the establishment of a distinct pathological condition which can only be repaired by the restoration to the general economy of the disfunctioning or absent tissue. Gonadectomy, on the other hand, does not result in a diseased state: the individual becomes altered functionally and structurally, but the change is not so far removed from normality as to constitute disease. The gonads are especially concerned in the development and maintenance of sexuality, and it can be stated that the secondary gonadic characters, which are the most prominent of the sex-dimorphic characters, develop only when in an otherwise healthy body the gonads are functionally normal and active.

It is abundantly established that an animal which is castrated at an early age, and into which at the time of this operation its own testes or those from another animal from the same or from a nearly related species are successfully implanted, will develop normally in respect of the bodily functional and structural sex characters. The prostate and penis in such animals develop so as to remain unexceptional. Partial or almost complete restoration of maleness is possible even in older animals castrated in early life, and the degree of restitution varies with the age of the individual at the time of castration and at the time of implantation, and with the length of the interval between the operations.

It is equally possible to restore femaleness in an individual from which the ovary has been removed by implanting ovarian tissue, and to prevent the sequelæ of ovariotomy—*i.e.*, of removal of the ovaries—by implanting the individual's own ovary or that of a similar or nearly similar biological form, at or about the time of ovariotomy. In such cases the womb does not atrophy, or it increases in size again, and in the human female menstruation returns.

It is established that it is possible to "feminise" a male by castration and subsequent implantation of ovarian tissue. The latent "female" sex-characters, for example, the mammary glands, are stimulated into activity, whereas the "male" characters, for example, the penis, remain under-developed, or become diminished in size and complexity.

It is established that it is possible to "masculinise" a female by ovariotomy and subsequent implantation of testis. The womb and mammary glands remain undeveloped or shrink, whereas the female erectile organ increases in size to such an extent that it resembles the male copulatory organ. It seems fairly clear, therefore, that the physiological action of ovary and testis are sex-specific, acting only upon those structures with which each is normally associated. It may be, however, that female tissue—*i.e.*, such as are 1X : 1A in chromosome constitution—respond preferentially to the physiological influence of the ovary, whereas male tissues respond preferentially to that of the testis. It is established also that the elaborated products of the gonads are not specific for each biological form of animal—chimpanzee testis can replace human testis, as is evidenced by the records of the recent rejuvenation technique.

It is established that it is eminently possible to produce an artificial hermaphrodite by combining ovarian and testicular tissues in one and the same body. A male with a normally functioning sex-equipment can, following successful ovarian implantation, come to possess well-developed mammary glands, and a female with a perfectly functioning reproductive system can harbour a testis graft which can proceed to the production of functional spermatozoa. Similarly, hermaphrodites can be produced through implantation of testis and ovary into a castrated individual.

It has been recorded that such experimentation is followed by the development of bisexuality in respect of the psychical characters, but this has not yet been finally established.

3. *Injection of Gonadic Tissue and Extracts.*—The results of injection have been conflicting. Definite effects upon the circulation, metabolism, nervous system, and on the sex-dimorphic characters have been recorded, but in the main they have been effects which can be obtained by injection of extracts of

animal tissues of all kinds, being characteristic of the action of proteins generally and not of gonadic tissues in particular. The effect of the extract must vary with the method of preparation and with the technique of administration. Moreover, it is not easy to reproduce the relation of gonad and body by injecting gonadic material, particularly if such an organ exhibits a rhythm in its functioning and if a quantitative action is involved. Though the evidence derived from injection methods is confusing, it can be said that this is due to imperfections in the methods of preparation and administration, and that there is nothing in this evidence which contradicts the point of view that the gonads, in their physiological functioning, direct the differentiation and ensure the maintenance of many of the sex-dimorphic characters.

It is seen that in the mammal the most distinctive sex-dimorphic characters are the secondary gonadic, and that for the development and maintenance of these the presence and action of functional gonadic tissue is necessary. The physiological action of gonadic tissues of the opposite sex causes the further development of incompletely differentiated structures to follow the direction appropriate to that sex, and, so far as is possible, renders the individual intersexual. Thus, the problem which faces the student of heredity is that which is concerned with the mechanism by which sex is determined. Such evidence as there is suggests in the strongest possible fashion that sex is determined by the chromosome-distributing mechanism and that initial differences in the chromosome constitution of fertilised eggs determine whether they shall be males or females. Sex being thus determined, the rest follows, each sex becomes equipped appropriately for the elaboration of eggs or sperm, for the transference of these to the site of fertilisation, and for the ante-natal and post-natal care of the young.

CHAPTER IV

VARIATIONS—INBORN AND ENVIRONMENTAL

THE student of heredity is concerned with the behaviour in inheritance of variations—deviations from the usual characterisation of the stock. The methods of experimentation devised to reveal the orderly segregation and recombination of hereditary factors transmitted from one generation to another have been described in detail. These methods quickly and clearly distinguish between dissimilarity that is inborn and variation that is but a modification due to the unequal impress of environmental agencies, even though they throw no light upon the processes by which the inborn variations have their origin. It can be demonstrated that certain variations are due to the action of particular agencies in the environment under which the individuals live and develop, whereas in the case of others no such correlation between experience and characterisation can be demonstrated. Such characters seem to have arisen spontaneously from causes within the organism. It is established, as has been shown, that in many instances these inborn dissimilarities are constantly associated with (1) demonstrable segregation and recombination of latent or previously unexpressed hereditary factors, (2) sudden changes or mutations in the hereditary material, or (3) alteration in the number or the arrangement of the chromosomes.

If a particular alteration in the environment produces modification of a varying character, it is probable that this variation is an environmental one; if it does not, then the variation is probably inborn. A gardener may notice amongst plants from the same lot of seed several which are very pale green or white, and he may note that these are the plants which are growing in a shaded part of the garden. If he exposes them to full sunlight, he notices that they become green like the others, and the inference is that the absence of colour in this case is an environmental dissimilarity, the result of a lack of sunlight. If he repeats this experiment with another seedling which is white, he may find that it never becomes green either in sunlight or in shade. In this latter case, the albinism is due to some inherent change which is quite independent of the experience of the plant.

It is noted that some characters of the individual are easily and profoundly modified by environmental changes whilst others are not. For example, European cattle introduced into South Africa or into Australia undergo changes in size and shape, but their colour markings and horns remain unaffected. Manifestly, variation in the first case is due to environmental causes, whereas dissimilarities in coat colour pattern is inborn. It is well known that differences in the kind and in the amount of food supplied to animals of the same family are responsible for marked differences in size. It is a fact that, if chickens of a breed which normally has yellow legs, skin, and beak, are fed upon white corn, these parts become white, whereas if yellow corn or green food is added to the diet, they regain the normal yellow colour. In other breeds, the legs and skin and beak are white and remain white, in spite of differences in the kind of food given. It is well known that animals living in colder regions develop thicker fur than those of the same kind living in warmer climates. It is also proven that animals living in environments in which there is a deficiency of the ultra-violet rays may exhibit marked deformities in their bones. Such would appear to be the cause of leg weakness in chickens. In addition to the agencies of the external environment which can be shown to produce dissimilarity amongst related individuals, there are other agencies within the animal which can produce similar effects. The system of ductless glands is a regulatory mechanism controlling harmonious growth. Dissimilarities in the efficient functioning of such glands as the thyroid, due to accident or to disease, lead directly to many distinctive secondary variations in the general characterisation. In certain areas, young pigs at birth commonly are weak, sickly, and completely hairless. The causal agent is a deficiency in the thyroid secretion of the mother, and the condition may be prevented by administering iodine to the pregnant sow.

The effects of environmental agencies in conditioning the development of an individual and of its characterisation, and the reappearance of these modifications in succeeding generations living under the same conditions, are such as to incline one to the opinion that new heritable characters are actually called into being by the impress of such environmental agencies. It has frequently been assumed that dwarf races of animals and plants are descended from ancestors which for many generations were subjected to adverse conditions such as inadequate food supply, or cold, wretched climate, which are known experimentally to limit growth. Such characters as hornlessness in cattle or taillessness in cats are regarded by some as having had their origin in the practice of dehorning or docking the tail continually for many generations. This question as to whether or not dissimilarity induced in individuals by the action of the environment may become inherited is of profound importance not only to the student of heredity and to the breeder, but also to the student of evolution.

Though the existence of any mechanism by which such acquired characters may be transmitted to the germ cells has not yet been demonstrated, there is no necessary or inherent impossibilty of its existence. The question to be answered by experimental evidence is simply whether such characters so provoked do or do not become inherited. It is well known that certain dyes given in the food or injected beneath the skin of the hen may find their way into her eggs and appear in the tissues of her offspring. This is certainly a case of transmission from one generation to another, but it is equally certain that such transmission does not represent inheritance in the strict sense, since the egg served simply as the vehicle of transmission of a foreign substance. A similar method of transmission occurs in the case of several diseases, of which the best known is syphilis. The infecting organism itself passes into the ova of the syphilitic mother, and is passively transmitted to the progeny. Another instance is the bacillus of white diarrhœa in chicks. In these cases it is evident that there is no change in the hereditary constitution: an acquirement has been transmitted along with the hereditary material, but has not become a part of it.

Very remarkable variation can be induced by the administration of certain poisons, stimulants, and other chemical agencies. Monstrous and bizarre forms may be produced in fishes, for example, by slight changes in the proportion of various salts present in the water. One-eyed, partially double, and both dwarf and giant forms have been produced in this way, but there is no evidence that such variations are inherited.

In the guinea-pig very abnormal fœtuses and living offspring have been obtained following the administration of alcohol to the parents. These dissimilarities are to be regarded as the result of direct injury to the germ-cells of the parent by the alcohol. They are reproduced in the non-alcoholised offspring of the defective animals, because these had their origin in the injured germ-cells, showing that such injuries may persist for more than one generation. Other experiments with alcohol have shown that they may act selectively to kill the weaker germ-cells and to allow the stronger to survive. In addition to killing off the weaker germ-cells and embryos, the poison may produce injuries of a general nature which may persist in the descendants, but not through an indefinite number of generations, for the effect of injury gradually wears off as fewer and fewer damaged germ-cells are elaborated.

Experimental dehorning of cattle, docking of the tails of horses, sheep, and dogs, circumcision, the artificial deformation of feet and heads practised by different peoples through many generations, have not been followed by any permanent effect upon their descendants. The evidence is such as to make possible the statement that the effects of mutilation are not inherited, but even here it is necessary to be cautious, for it is possible, though not proven, that some sorts of mutilations may set up reactions within the animal body which may affect the germ-cells. Thus, injuries to one eye may induce the formation of substances in the blood under the influence of which the remaining eye may be affected, and several investigators hold that it is possible that these so-called antibodies may also affect the actual hereditary factors for the eye characters in the germ-cells themselves, so that the individuals which arise from them may exhibit the defect.

Variations in the nutritive value and in the quantity of food supplied to animals are certainly responsible for differences in the size of their progeny. Underfed animals frequently bear smaller offspring, and the effect may persist for one or two generations, but ultimately it disappears. When parental starvation has produced an effect upon the size of the offspring, this is to be interpreted as the persistent effect of injury to the germ-cells, which, as in other cases of such parallel induction, wears off in future generations.

Experiments have shown that a qualitative change in food, though productive of a modification of a characterisation of the individual so fed, is not followed by truly inherited dissimilarity. It has been frequently noticed that darker forms of some variations of moths occur in the industrial districts of Great Britain, and the origin of such melanic types has been referred to the moisture of the environment, to the darkness of the background, and also to a direct inherited effect of the food, the leaves on which the moths feed being covered with metallic salts, the by-products of the local industries.

Though there is much that is suggestive in the experimental evidence concerning this question, it has not yet been definitely proven that melanic forms have originated in this way. It may be that amongst such moths are individuals which, in virtue of their hereditary constitution, will become melanic when so fed, and that the melanic form has a survival value in such unfavourable surroundings in urban industrial districts.

Recently some very important experiments have been made to invoke heritable modifications by the use of sera, X-rays, and radium. It has been known for a long time that the introduction of foreign substances such as proteins or bacteria into the blood of an animal may induce the formation of antibodies in the blood, substances which tend to destroy or otherwise inactivate the introduced substance against which they are developed. In one experiment, fowls were made to produce antibodies against the lens tissues of rabbits' eyes by repeatedly injecting them with the pulped material from the eyes of young rabbits. The blood of fowls containing these lens antibodies was then injected into pregnant rabbits. Amongst the offspring of mothers so treated several young were born which showed various defects of the eye, and these defects proved to be inherited both when the defective-eyed rabbits were bred to their own relatives and when they were crossed to unrelated rabbits with normal eyes. The explanation offered is that these lens antibodies, either directly introduced in the blood of pregnant rabbits or introduced through the fowl's blood, attack and injure the lenses of the developing fœtuses whilst these are in the body of the treated mother, and that they affect at the same time some of the germ-cells of the embryo rabbits in the same specific way, provoking the origin of a new factor for defective eyes.

The difference between these experiments and others is that, though in both parallel induction is suggested —*i.e.,* that both the body cells of the treated individual and the germ-cells are affected by the agent at the same time, it is assumed in this particular case that the effects upon the germ-cells are specific, and not of the nature of a general injury such as is produced by alcohol.

Most recently, by the use of X-rays, the frequency of the incidence of the already known mutations in Drosophila has been increased some 150 times, and also new forms, hitherto unknown, have appeared. This work possesses very considerable significance, because it would seem to be the first instance of the production of new hereditary factors in the case of a material the hereditary constitution of which is relatively very completely known, by the employment of an agency which can be controlled in its strength and action. To increase the frequency of mutation is enough to produce new types.

Many trades are responsible for the acquisition of peculiar characterisations in the human. It is possible to identify the shoemaker or the tailor by peculiarities of the muscles and skeleton. But these peculiarities are not inherited. In the ostrich, however, it has been shown that thickenings of the skin are developed on those parts of the body which come into contact with the ground when the bird is resting. Such thickenings are provoked by local pressure, just as corns are in the human, but certain of them appear in the embryo before the hatching of the egg. The thickenings are developed before they are used, and the question arises as to whether the effects of use have become transmitted by the ordinary mechanism of inheritance. It certainly is true that it would seem to be a plausible explanation that through many generations of ancestors these peculiar adaptive responses formerly acquired by the individual during its own lifetime have become gradually accelerated in the time of their appearance in development, so that now the thickenings appear before they are used and are present in the embryo. But, unfortunately, it is impossible to put such an explanation to the test of critical experiment.

It is possible, however, to test by experiment such a problem as the inheritance of educability. Mice have been taught to come for food at the sound of a bell. The offspring of mice so trained are reported to have learned the trick more easily than did their ancestors. With continued inbreeding in the laboratory, the generations learned to associate the sound of a bell with the offering of food more and more quickly. But this is not a straightforward case. Great need for caution exists in the interpretation of such data. Increasing ease of teaching may possibly be explained as a result of a gradual disappearance of vigour and wildness. In another experiment entirely negative results were obtained, for the descendants of rats which had been taught to find their way through a maze required just as much training as did their ancestors.

It would seem that few or none of the variations which are ordinarily spoken of as environmental have been shown to be truly inherited. It is quite certain that many of them are not inherited. This conclusion has a great theoretical importance, for it would seem to indicate that most of the inborn characters with which the student of heredity deals have not originated as direct responses to the impress of environmental agencies, and that the rôle of the environment in guiding evolution is not that of a creative force. Further, it means that plant, animal, and human improvement cannot proceed either slowly or permanently merely through the improvement of the environment. It is eminently possible to permit a fuller expression of the hereditary constitution of an individual by providing an optimum environment, but it would seem to be a fact that it is impossible to add new hereditary factors to one's equipment by creating and living in such an environment.

CHAPTER V

HEREDITY AND ANIMAL AND PLANT BREEDING

In the case of the domesticated plants and animals, all breeding operations involve the control of natural processes. A necessary prerequisite of such control is an understanding of the general principles of the science which concerns itself with reproduction. Our knowledge of the principles or laws of inheritance which (1) affirm the existence of paired elements, factors, or genes, that have a high degree of constancy and that segregate sharply from each other in inheritance; and (2) define the ways in which these units are distributed amongst the progeny in cases of bisexual reproduction, has now reached the point when the animal and plant breeder may begin to incorporate it in his breeding practices. Any independently inherited character, the mode of inheritance of which has been demonstrated, no matter where found, can be combined with others of a similar nature, or, on the other hand, through breeding can be deliberately eliminated from the stock. Control of this sort is necessarily limited by the degree of our knowledge of the mode of inheritance of the characters concerned, and this can only be gained through sufficient experimentation. In the case of such forms as have been extensively used as experimental material, the breeder is able quickly and confidently to produce any given combination of characters. It will be noted that thus far the breeder has not been able to cause characters to appear, and control merely implies the power to create new combinations of such heritable variations as have already appeared. For the present, it remains a dream, probably shortly to be realised, that man shall acquire the power to produce at will new heritable variations, but in spite of the present lack of power to produce such, the power to guide the formation of new groupings of characters has already produced results of very distinct value to the breeder and to the community.

One outstanding example of the application and of the usefulness of Mendelian principles in practical breeding is that of Professor Biffen, of Cambridge, who by typical Mendelian methods produced a wheat exhibiting the desirable qualities of heavy cropping capacity, hardness of grain, and immunity to the disease, rust. This new wheat, which exhibits this combination of desirable characters that previously had existed separately in different wheats, will, without doubt, prove of the greatest benefit to British wheat-growers.

Many other instances of such direct application to simple Mendelian principles to plant and animal breeding could be cited, but were this done one would, perhaps, be over-emphasising the importance of this method of application. In the great majority of cases outstanding breeds and varieties of animals and of plants were not produced by expert biologists, but by practical breeders, who certainly were not guided in their practices by a knowledge of the more recently discovered principles of inheritance. There is no doubt that the success of such breeders has been due to the fact that the methods they adopted were essentially in accord with the principles of inheritance that have recently been discovered. Since these breeders, though they certainly must have recognised certain rules of breeding, did not disclose a scientific law, they were not able to generalise and to predict and thus to shorten the methods of improvement for themselves in other fields or for breeders of other kinds of animals and plants. In the majority of cases the outstanding breeds and varieties had their beginning in the fortunate and fortuitous appearance of one or more superior individuals which, being manifestly superior, were very largely used for breeding, and in the very rigorous selection and testing of the progeny of these. It would be mistaken, therefore, to claim too much for the direct employment of the new science of heredity. It is probable that the greatest contribution of this science will always be the results of an appreciation of its principles.

The achievements of the past have been gained through the application of the method of trial and error, and they owe much to the rare insight of a few outstanding men. The successful breeders of the past are outnumbered enormously by men who have failed. Even to-day it will be found that the outstanding men in live-stock and plant breeding cannot communicate their great art to others. In science the personal factor counts for very little, for its facts are such as can be verified by anybody amenable to reason. The forces of heredity exhibit remarkable constancy and regularity, and in the hands of the breeder they will remove chance from breeding operations. The principles of inheritance properly understood will prevent the breeder drawing false deductions from the facts that present themselves to him. They will explain his results and allow him to predict the consequences of his operations. Most of the qualities of domesticated animals and plants which are of really serious economic importance are, in their mode of inheritance, extremely complicated. Such characters are mainly concerned with function, with performance; examples are egg yield, size, conformation in farm animals, disease resistance, rate of growth, quantity and quality of fruits. All such characters as these depend on very many factors, some certainly inborn and many others environmental, and the relative parts played by these two kinds of factors are still unknown in most cases. Until it has been possible to distinguish the environmental from the inborn variation, it must remain impossible to speak with confidence concerning the details of inheritance.

There is plentiful evidence that heredity plays a very important part in determining both the quantity of milk and its quality, particularly in respect of proportion of butter-fat; but direct experimental evidence concerning the mode of inheritance of milk yield and fat percentage is as yet not sufficiently abundant. Milk production is, indeed, a complicated affair, for it is influenced by such inborn factors as affect the rate of growth, the size, and the degree of functioning of the reproductive organs. So it is that at the present time the help that the breeder of dairy cattle can obtain from the professional biologist is very limited. However, there is every reason to hold that ultimately this important problem may be attacked by the same methods which have been successful in disclosing the mode of inheritance of simpler characters.

The chief method of the progressive breeder in the improvement of his stock has ever been the selection for breeding of those individuals which approach most nearly to the type that is held by him to be the ideal, and this selection has always been based upon the *appearance* of individuals or groups, commonly without reference to ancestry, progeny, or to the degree of relationship of the individuals concerned. More recently the introduction and spread of the pedigree breeding methods have emphasised the value of a study of ancestry in the selection of individuals for breeding. For the purpose of changing the average characterisation of a stock, selection has usually been applied to such characters as show a quantitative variation. The breeder has continuously selected individuals which showed a slight variation in the desired direction in respect of such characters as increased size, improved shape or pattern, and remarkable results have been achieved. The breeder quickly found that some of these characters yielded very rapidly indeed to such selection and that progress is rapid up to a given point, after which further selection proves ineffective. In other instances the experience has been that such selection yielded no advance, and so it is that up till recently there has been no general explanation of the manner in which selection accomplishes its aims or how it is in certain instances it fails to do so, and the result has been that there have been confusion and disagreement concerning the efficacy of the method.

Within the last twenty years, however, the explanation has been disclosed. It has been shown quite conclusively that selection is only followed by a movement in the desired direction when applied to a population that is heterozygous for many of its characters, and the result of such selection is isolation of individual homozygous in respect of the desired characters. It has been shown, further, that when the individual is homozygous for all the characters for which selection is being practised, further selection is without avail, for the homozygous character is necessarily true-breeding. Thus it is that selection is relatively ineffective in changing the breed characteristics of a well-established variety of animal or plant, and the effectiveness of selection depends on the presence of inborn variability. That selection is usually so successful a tool in the hands of the breeder is to be explained by the fact that in respect of the characters which are held to be desirable domesticated animals and cross-fertilised plants are so heterogeneous or heterozygous that selection practised on ordinary stock is more or less bound to be followed by some advance in quality. After the initial period of selection is passed, however, the stock approaches a condition of homozygosity, selection becomes less and less effective, and the breeder must then seek some other means of improving his stock. Selection creates nothing, but merely sorts out individuals which are homozygous for the characters for which the breeder is aiming. It alters the average characterisation of a stock by altering the proportions of the different hereditary constitutions within it.

Another lesson that is to be learned from the facts of inheritance is that appearance alone is not a reliable guide to breeding ability and that a more certain method of estimating the breeding quality of an individual is the progeny test. Breeders have adopted this test very largely, and in doing so they have recognised that permanent improvement must be an improvement in the hereditary constitution of the individual. The best evidence concerning the hereditary constitution of an individual is to be obtained from a study of its progeny. The father is judged by the appearance and by the performance of his son. Amongst animals the breeding value of sire or dam is best estimated by a sample of its early progeny. It is applied most readily to males because of the greater number of offspring which may be obtained from a single male and because the flocks and herds may be improved with greater speed by this means than through the selection of superior females. Those males which beget the best progeny, judged by some particular standard, are retained; the others, even though they may be in general appearance the better specimens, are discarded.

The science of heredity has also suggestions to offer concerning the relative merits of different systems of matings. All methods which lead to the production of uniform and valuable varieties of animals and plants involve sooner or later the mating of related individuals. Inbreeding, in practice, is the term restricted to describe the matings of close relatives—*e.g.*, brother and sister, parent and offspring, and matings between relatively unrelated or only distantly related individuals are described as instances of outbreeding. Matings involving individuals belonging to different breeds or varieties are described by breeders as examples of crossbreeding. Line-breeding involves matings between relatives in an attempt to increase or concentrate in one line of descent the hereditary constitution of one or of a few individuals. All these systems can be grouped under the two headings of inbreeding and outbreeding, these differing one from the other only in the degree of relationship of the individuals concerned. The system of inbreeding has been deliberately employed by animal breeders from the time when first the breeds were improved, for the history of the modern breeds of domesticated stock shows plainly that during their formative periods some degree of narrow breeding was ever practised, and it would seem, indeed, to be an essential to the attainment of outstanding successes in breeding. Inbreeding is therefore not necessarily harmful, but can be definitely advantageous, leading to the development of a uniform and true-breeding stock. It is equally true, however, that benefit does not always follow this practice, for in certain cases there has been, and under experimental conditions still is, disappointing regression, diminution of vigour, lowered powers of resistance, decreased fertility, even reduction in size.

Since the results of this system of mating have been so contradictory, it has been impossible until recently to provide an explanation of the processes involved. In human societies this disagreement has resulted in laws and customs as diverse as those which forbid marriages outside a restricted group of relatives and those which forbid matings between relatives altogether. Inbreeding has been practised occasionally in the case of the human race, as, for example, in the royal families of Egypt, and, to a lesser extent, amongst the royalties of Europe. But laws and breeding practices vary, because inbreeding has not always produced the same results. Even though the facts vary, however, there has grown up amongst students of heredity a considerable degree of unanimity concerning the principles involved, and a general interpretation has now been promulgated which explains the conflicting results in scientific terms. This has been brought about through the accumulation of data from controlled experimentation and through the scientific analysis of the evidence thus obtained. It is now established that the effects of inbreeding depend not upon any pernicious attribute of this system of mating, but upon the hereditary constitutions of the individuals involved. Inbreeding has but one demonstrable effect upon the stock subjected to its action, and this is the isolation of homozygous types. The average specimen of the domesticated animal or cultivated plant exhibits a great multitude of characters, and corresponding to these characters there are in the hereditary constitution of the individual factors which may be present in the simplex or in the duplex state. It can be stated confidently that no individual is duplex for the factors for all the characters which it exhibits. Inbreeding leads to a rapid increase in homozygosity, and when this state has been achieved, stability and uniformity will be reached. But as this process proceeds there is an inevitable reshuffling of all factors, and so it is that individuals will appear which are homozygous for characters which are definitely deleterious to their possessor. The weak, sterile, and abnormal individuals which appear amongst the offspring of an inbred line are such as have received during this process of the reshuffling of the hereditary factors those which correspond to undesirable characters, these factors ultimately coming to be present in the duplex state. Such individuals will be eliminated, whilst, on the other hand, others which, thanks to this same process, have come to possess the factors for desirable characters in the duplex state, will show improvement over their ancestors. Rigorous selection from amongst these improved types will isolate strains that will compare very favourably indeed with the original stock.

Consanguinity in itself is not a bar to a mating. If inbreeding results in disappointment, all that has happened is that disadvantageous characters, the ingredients of which were previously hidden and unexpressed, have been brought to light. Inbreeding thus purifies a stock. This system of mating may be disastrously expensive if the ingredients of hereditary combinations which result in undesirable or nonviable types pre-exist. But, on the other hand, such individuals as have been made homozygous for the desirable characters will be far more valuable material in the hands of the breeder than the stock with which he started, for, in virtue of their hereditary constitution, they must now breed true for this character. The principal effects of inbreeding both in animals and plants are (1) a reduction of variability in the expression of inherited characters within inbred lines or families; and (2) a usual, but not inevitable, decline in general vigour.

The results of inbreeding also provide an explanation of the phenomenon known as hybrid vigour. Since the earliest times animal husbandmen have been familiar with the observed fact that the first crosses of different breeds or races of the same kind of farm animals commonly exhibit a remarkable sturdiness. This hybrid vigour is manifested in different ways. Frequently the crossbred offspring are stronger, attain a larger size, mature in a shorter time than either parental stock, and not uncommonly they possess notable powers of resistance to unfavourable conditions. Livestock breeders are well acquainted with this superiority of the first-cross for many commercial purposes. As an example, the breeder of cattle will doubtless quote the case of the blue-grey, frosty-coated cattle of Scotland, a combination of black Galloway or Aberdeen-Angus with white Shorthorn, which have long been known and deservedly esteemed for their large size, goodly proportions, and early marketability. The shepherd will extol the qualities of the Blackface Down crosses so reasonably popular on account of their quick growth and general usefulness. The breeder of pigs will remark that the most excellent bacon pig of Denmark is itself a first cross, whilst the utility poultry breeder will confess, in argument, that the results of the laying trials of recent years have given him cause to examine afresh the question as to whether or not the purebred bird can hold her own against her crossbred relative in the matter of egg production.

This phenomenon of increased vigour through crossing is of profound interest scientifically as it is of importance practically: it has engaged the attention of the scientific man since before the days of Darwin. It has been abundantly demonstrated that crosses between unrelated stocks of such diverse living forms as the silkworm, fish, guinea-pig, and mouse, between different varieties of the same plant, between different species of animals, for example, horse and ass, ass and zebra, cattle and zebu or bison, and between different species of plants, commonly result in offspring remarkable for luxuriant growth, increased reproductive ability, hastened maturity, increased length of life, greater hardiness, better viability, and increased powers of resistance to disease. It can be stated without qualification that the evidence from scientific laboratories completely confirms the conclusion of the practical man that the secret of successful breeding is to keep on improving the pure breeds by selection, and, in order to achieve certain results, to cross but only with discretion.

From this experimental work, critically planned and carefully conducted, the following facts have emerged:

1. The crossbred does not invariably exhibit this hybrid vigour. Any and all crosses will not produce offspring of greater excellence than their parental stocks.

2. In those cases in which hybrid vigour is exhibited by the first-cross individuals, further crossing of these hybrids results in a manifest decrease of this vigour in subsequent generations. The second crosses are not so vigorous as their hybrid parents. Hybrid vigour is the peculiar possession of the first cross.

3. In order to obtain this hybrid vigour in any degree, it is essential that the two parental stocks shall be unrelated, purebred, and that each shall itself be possessed of qualities that, in the opinion of the breeder and in relation to the object of the crossing, are excellent.

Darwin years ago convinced himself that it was not the mere act of crossing that was responsible for the greater growth of the plants with which he was examining this question of hybrid vigour. He found that pollinations made between different flowers on the same plant or between different individuals of the same ancestry brought about no change, and he satisfied himself that it was the bringing together of diverse elements from compatible but somewhat unrelated types, for example, when dissimilar varieties, native to different geographical regions, were united, that the most noticeable results were secured.

The explanation of the demonstrable and verifiable facts concerning hybrid vigour is simple. It will be agreed that in general there is a tendency for the qualities of the parents to be expressed in the offspring. This is the basis for an understanding of the vigour derived from crossing. Every individual is a mixture of good and bad, of desirable and undesirable qualities. No one is good through and through. In crossing, the qualities of the two parents are pooled; the deficiencies of one parent can be made good by the excellencies of the other, the good of one can be reinforced by the good of the other. If an individual is deficient in any way in its hereditary constitution, there is a good chance that its needs may be supplied when it is crossed with other individuals, since it may well be that their deficiencies are not of the same kind—a pooling of the hereditary resources may easily yield a combination that is better than either of the ingredients alone. Hybrid vigour is based in heterozygosity.

If this interpretation is correct, and there is no reason to question its validity, then it follows that undesirable qualities are inherited as well as desirable, and that in order to secure this hybrid vigour, it is necessary that the individuals used for the production of the first cross shall be as excellent as may be and that the good qualities of the two shall be, as far as is possible, complementary. The qualities that are concerned are not those of form and of structure, but are the physiological, concerned with the kind and the rate of functional activity, and so it is that hybrid vigour, as great as that which results from the crossing of different species or breeds, can follow the crossing of individuals from different families or strains of one and the same variety or breed. The breeder who keeps his family lines distinct can, by appropriate matings, secure all the hybrid vigour he seeks, without calling on the aid of other stocks.

Since for the production of hybrid vigour the qualities of the two parties must be compensatory and complementary, it follows that all matings cannot be expected to yield it and that many may end in disaster. Experimentation alone can decide whether a particular mating will be attended by hybrid vigour in the offspring. Since it is the pooling of qualities that leads to hybrid vigour, and since breeding implies the assortment and redistribution of these qualities among the offspring, it follows that the further breeding of the first cross must lead to reduction in general sturdiness.

The facts concerning hybrid vigour that are to be emphasised are these: It is the peculiar property of the first cross. For its production it is necessary that the parental individuals shall be pure-bred and themselves as fine specimens of their breed or herd as may be. Without the pure-bred, there cannot be the cross-bred of any worth. The first cross, deliberately bred for a definite commercial purpose, must not be used for further breeding.

CHAPTER VI

HEREDITY AND HUMAN AFFAIRS

Man undoubtedly is exceptional in many ways, but nevertheless is essentially similar to those forms of life which have been the experimental material of the student of heredity. The outstanding fact which emerges from a study of the laws of inheritance is that they apply with equal force to all kinds of living things, and it is this universality of the laws of inheritance which allows one to hold the view that that which man has done in the case of domesticated animals and cultivated plants he can do to himself should he so wish. In the case of his animals and plants, man usually has set himself the task of building a type that would flourish in a particular set of environmental conditions which were known before he set out upon his task. It is difficult to discuss breeding better men until the kind of environment in which this improved type shall live has been defined. In the case of the human subject, controlled experimentation manifestly is impossible, and data have to be collected by the less exact method of analysing family histories. It can be stated that in man there is a multitude of characters which in their mode of inheritance simulate exactly those which have been discussed earlier in this book. This being so, it is reasonable to assume that the mechanism of inheritance in man is exactly the same as that which has been shown to exist in other forms.

Of the characters which in their combination constitute the human subject, the more interesting and the more important are those which are concerned with man's mind, for if it can be shown that intellectual ability, for example, is inherited in a fashion equivalent to that of eye colour, then, indeed, heredity must play an all-important rôle in human affairs. So far the difficulty in this matter of dealing with the mental characters is that there is no exact definition of dissimilarities. Everyone can bring to mind from his personal knowledge families in which high intellectual ability, mechanical genius, outstanding musical or mathematical talent, or their opposites, seem to "run in the family" and characterise some or all of its members generation after generation. It would seem, indeed, to be the case that parents of outstanding ability are more likely to have children superior in their intellectual endowment than are parents of unexceptional worth. It would seem to be the case also that the feeble-minded beget feeble-minded. But in such cases great caution must be exercised lest one should disregard the very powerful influences which social environment and education must exert during the development of the mental qualities of man. There can be no gainsaying that illegitimate and outcast children will be far more likely to develop vicious traits than will those brought up in favourable environments.

The only satisfactory material of the study of heredity in the human subject, since this study must be observational, would appear to be cases of identical twins. These are twins which have had their origin in the division of the same fertilised egg and which, therefore, possess precisely the same hereditary constitution. They are always of the same sex, and in their physical characteristics are so much alike that commonly they cannot be distinguished by their acquaintances. It is noteworthy that this resemblance extends also to general mental ability, and in the case of identical twins reared apart from a very early age, dissimilar experience does not completely over-ride the inborn similarity any more than does similar environment overcome inborn dissimilarity in the case of children of the same family and social group.

The conclusion seems justified that, to a very considerable degree, mental characters, particularly those involving general ability and capacity, are primarily based in hereditary factors. Ability as such is not inherited, but that which is inherited is an inborn capacity or predisposition. The end-result will be determined in great measure by environment and by training. What one may be would seem to be determined by one's hereditary constitution; what one is is the expression of one's constitution as conditioned by the forces of environment and education. An individual of moderate natural endowment who has developed this to its fullest expression may be a more valuable member of society than is one of greater gifts who, through lack of opportunity, has allowed them to lie fallow. But from the point of view of the race, it may well be that the latter may prove to be the better parent. It would be impolitic to over-emphasise the importance of heredity in human affairs, for the reason that our knowledge of the mode of inheritance of human characters is still very elementary and needs much amplification before there can be any application of the principles of heredity to the deliberate improvement of the race.

There can be no doubt that the environment is not of paramount importance in determining the characters of individuals, of societies, or of races. The forces of environment are but one system in the mechanism which produces the characters of mankind. Slowly but surely it is becoming recognised that all efforts to deal with the problems of modern society, and especially all proposals for the improvement of the race, must include not only schemes for the improvement of education and of the material aspects of civilised life, but that they must also include as a basic feature suggestions for the improvement of the hereditary constitution of the stock. In this recognition the modern eugenics movement, which has as its object the improvement of the inborn qualities of man, had its origin. Eugenics is now becoming firmly established as an applied science utilising the facts and the theories which have been disclosed by the general work upon heredity, and it has already defined its problems and has made suggestions as to how perchance these may be solved.

During the last century there has been an extraordinary increase in the size of the populations of all civilised countries, and one of the problems with which the applied science of eugenics is concerned refers to the fact that this increase has been *differential*, the rate being lowest among those sections of the population which, judged by accepted standards, are the most highly endowed mentally, and highest amongst the relatively defective and less well-endowed classes. From the former class are recruited the majority of the leaders in those vocations which are regarded as being of the greatest social value, whilst from the other has come a large proportion of the inmates of State institutions for the feeble-minded and for the criminal. This differential increase in numbers is a reflection of the fact that the birth rates of these two classes have become markedly different, the individuals of the lowest social value consistently having the highest birth rate.

Doubtless much of this differential birth rate is, in its origin, economic rather than biological, for the ambitious and the well endowed have ever been forced by economic causes to seek a more expensive standard of living and, as a means to this end, to avoid any considerable increase in the size of their families. Such restrictive factors have not operated to limit the birth rate of the defective elements in the population, and these, through the increasing care exercised by society for the benefit of the weakly and of the subnormal, have found it possible to survive and multiply, since there is no elimination of the relatively unfit by any selection, natural or artificial. There can be no doubt that amongst the feeble-minded there are many who exhibit this condition because of their organic inheritance. There is evidence that such inborn feeble-mindedness is recessive to normal mentality, so that there must necessarily be in a population many more individuals who appear normal but who carry recessive factors for the feeble-minded condition than there are of those who actually show it. So long as such carriers marry into stock that is free from this defect it will not appear in their progeny, but it will do so inevitably if they mate with individuals like themselves in the matter of their hereditary constitutions. The inmates of gaols and reformatories may or may not belong to a criminal class, but modern methods of examination have shown that in many cases a very considerable proportion of such populations consists of feeble-minded individuals. The paupers, tramps, beggars, and others, who are unable or unwilling to support themselves and must depend on institutional aid, are in many cases nothing more than instances of defective inheritance. Improved economic and social conditions would, without doubt, reduce the numbers of this class by removing from it those who are victims of circumstance, but when this had been done there would still be a large residue which, because of its inheritance, would remain on the border-line of self-supporting existence. The contribution to society of such stock as this is so small that its elimination would be advantageous to society.

From the purely economic point of view, the burden that this large group of defectives places upon society is very considerable. Moreover, the cost of the care of these defective elements in a population is steadily increasing, not only actually, but relatively. This is partly due, no doubt, to the extra cost of the better care now given to these unfortunates, but much of it would seem to be due to the fact that year by year these classes of the population are growing and are coming to constitute an ever-larger element of the population. It is safe to say that feeble-minded marries feeble-minded more often than normal, that pauper marries pauper, and that deaf-mute mates with deaf-mute, and that the birth rate amongst these groups is at least twice that of the professional classes.

If society can decide what types of individual it wishes to eliminate as being inferior in inheritance—and this is a task which must prove to be an exceedingly difficult one—then there are certain methods by which it may achieve its aims. In the first place, a sound and well-informed public opinion is a prerequisite to any kind of action. Our knowledge of the rôle of heredity in human affairs is not yet sufficiently wide to warrant any vigorous propaganda for specific action. Manifestly the great bulk of the defective population cannot be eliminated by the drastic methods which are employed in animal and in uncivilised societies. Death will ultimately remove the defective individuals themselves, and society must confine its efforts to preventing them from leaving offspring to perpetuate their undesirable qualities. If this should be accomplished, the strains of defective germ-plasm will ultimately cease to be, and the problem will thus be solved with the least possible hardship.

An obvious method of achieving this end would be to prohibit by law the marriage of certain classes of individuals. There are precedents for such legal action —for example, that concerning the marriage of closely related individuals—but it is doubtful whether public opinion would support any drastic regulations concerning choice of mates. Moreover, it would seem to be the case that the class of individuals at whom such measures would be directed are less amenable to law than are the normal members of the population, and laws of this kind would be indeed difficult to enforce. Even at the present time the illegitimate birth rate amongst those groups which can be regarded as being defective in the matter of their hereditary constitution is high, and even if marriage were forbidden them, doubtless such individuals would still beget a very considerable number of offspring. The most direct method which has been proposed to dam this stream of defective germ-plasm is to render these defective individuals incapable of reproduction. This method of sterilisation, which indeed requires the enactment of laws which place limitations upon personal liberty, has been adopted in certain countries. It can be said, however, that in the majority of cases the laws have become dead letters, commonly for the reason that medical men have a very real difficulty at the present time in selecting the proper cases for such operative interference.

A method which combines elimination of defective stock with the care of living defectives is the segregation of these individuals in colonies and institutions, the sexes being kept entirely separate from each other. Such colony units, which include imbeciles and idiots, are in part self-supporting through the practice of agriculture and of simple trades. The defectives are thus enabled to make some contribution to the welfare of society and, at the same time, are prevented from leaving offspring behind them. The difficulty has been that probably such colonies at the present time include only about 10 per cent. of the defective stock in a country, during the reproductive period of the individual, and to extend such treatment to all would involve expense that no country could face.

Whatever may be done in the case of the defective individual, there still remains the problem of the carrier. It has been estimated that 10 per cent. of a population are carrying recessive factors for various defects. It would take an exceedingly long time, therefore, for the most careful and thorough segregation to eliminate this defective inheritance. Such segregation on the whole seems to be the most humane and effective method of restricting the multiplication of defective stocks, and if society is prepared to bear the expense involved, this is the method that probably will be adopted more and more widely.

It is probable that, with an increasing public eugenic conscience, individuals who know that they come from tainted stock will refrain from reproduction. It is possible that a state may find it desirable to endow celibacy or childlessness in the case of such individuals.

Another problem which is more difficult in its solution is that which is presented by the relative decrease in the numbers of that portion of the population which would seem to be, in the matter of its inheritance, the most highly endowed. The birth rate amongst such individuals is less than that of the population as a whole, and in many cases it is not high enough even to maintain existing numbers. There is no evidence that potential biological fertility is related to mental endowment. It would seem that the causes of this very low fertility rate are mainly economic. The problem is a difficult one, for it is far easier to prevent the reproduction of a given class than it is to induce a group to reproduce itself more rapidly. Various proposals have been made from time to time which admittedly aim at accelerating the reproductive rate of the highly endowed. Such have been partial exemption from taxation in the case of a man with a family; in other cases a bonus is paid for every child above a certain number. Bachelors in some countries are taxed. All these proposals are more or less unsatisfactory because no very definite methods have been devised for applying them to individuals who are definitely superior in virtue of their organic inheritance.

The ultimate solution of the problem cannot be obtained by legislation, but must work itself out through the development of an enlightened and conscientious public opinion, which will encourage individuals of good natural endowment to raise families large enough to ensure that their valuable heritage may be transmitted undiminished. Evidence is not lacking that public opinion and private conscience are awakening to the importance of this problem, and that the intelligence and moral sense of the human race will succeed in solving it. There can be no doubt that any attempt to develop a standardised " superman " by an application of the methods of animal and plant breeding is bound to fail. Improvement in human stocks will come (1) when the standard of the ideal has been defined and has been shown to be biologically attainable and worthy, (2) when the ideal environment has been defined and secured, (3) when mankind recognises that man can and must control his own further evolution. Men and women will then deliberately become parents because they wish to share in the great adventure of producing children even better equipped than themselves to continue the conquest of the environment of man and of man himself.

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EMBRYOLOGY

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EMBRYOLOGY

THE STUDY OF ANIMAL DEVELOPMENT

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EMBRYOLOGY

CHAPTER I

THE GERM-CELLS AND FERTILIZATION

THE word Embryology (Greek ἔμβρυον, the fruit of the womb) signifies the study of the growth of the baby inside the womb of the mother, but the ambit of the word has been extended so as to cover the study of the growth of animal germs of all kinds, whether those germs develop in the open, like the egg of a frog, or within a hard egg-shell stored with nourishment, like the egg of the hen, or, finally, within the womb of the female drawing nourishment from her blood, like the egg of a woman. Embryology thus becomes the study of development in general, and in our judgment it is the most interesting study in the world, the very core and foundation of biological science, and all the other divisions of that science rest on it. If we take, for instance, the fashionable science of Genetics or Heredity we encounter at once the fact, often overlooked, that the young do not spring fully formed from the bodies of their parents, like Minerva from the head of Jove, but develop from comparatively simple germs, and only acquire the features which they are said to inherit from their parents at the termination of a long period of growth. If we turn to the science of physiology, which as a working hypothesis regards the organs of adult animals as machines, we have to explain the fact that these supposed machines have somehow been fashioned out of formless semifluid protoplasm and have acquired their powers gradually as growth has proceeded. The science of embryology is conventionally restricted to the animal kingdom: plants, of course, also develop from germs, but their bodies are so much simpler than those of animals that the study of plant embryology is not separated from the rest of botany.

Confining ourselves, then, to the animal kingdom, we find that there are two great grades of animals. In the lower and simpler grade, the mother disappears in the act of reproduction by dividing herself into a number of young; such animals are termed *Protozoa.* In the higher grade, reproduction is effected by the separation of small portions termed buds or germ-cells from a " body " which persists, and these animals are termed *Metazoa.*

The word " cell," as used in zoology, signifies the ultimate unit of living matter; it may be compared to a brick of protoplasm containing a nucleus, and it is separated from neighbouring bricks by a thin flexible membrane known as the *cell-wall;* if the nucleus be deprived of protoplasm, or the protoplasm be separated from the nucleus, both perish. Now the bodies of Protozoa, however big they may become—and some of them reach the size of a halfpenny—are never divided into cells; the smaller, which have only one nucleus, may each be compared to a single cell; the larger may have hundreds of nuclei, but their protoplasm is not segmented in accordance with the number of nuclei and hence does not consist of cells. In Metazoa, on the contrary, not only are their bodies divided into cells, but these cells are of at least two kinds, and the cells of each kind are arranged in sheets or masses, the components of which co-operate to perform the same function. Such sheets are termed *tissues;* in the simplest Metazoa there are two of these, viz. an outer one termed *ectoderm* which constitutes the skin, and an inner one termed *endoderm* which forms the lining of the alimentary tube or gut.

Embryology by custom deals only with Metazoa. The development of the larger Protozoa is not at all well known, and the smaller species remain at every stage of their life-history at the level of a single cell.

If we now take a comprehensive view of reproduction in the Metazoa we find that this can be effected in three ways, viz. by fission, by buds, and by germ-cells. *Fission,* or the division of the mother into two, is, as we have just seen, the method of reproduction adopted by the lowest Protozoa, but it crops up occasionally amongst Metazoa—even amongst those as highly organized as the earthworm. In some marine (Syllidæ) and freshwater (Naidæ) allies of the earthworm the mother develops across her body a zone of small actively growing cells. This is termed a "*zone of fission,*" and it grows gradually into a new tail in front and a new head behind. The mother then divides into two, the front half appropriates the new tail and the hinder half adopts the new head. In some cases, for instance in the worm Myrianida, the front half of the original mother, before separating from the hinder half, develops a new zone of fission in her hinder end; this develops in turn into a new head and tail: and in front of the new tail a third zone of fission develops, and this may be repeated fifteen or twenty times. The final outcome is that there is a large anterior person equipped with the mother's head, dragging behind her a chain of about twenty smaller persons, of whom the most developed is the hindermost, which is equipped with the original mother's tail. These persons drop off one by one and lead independent lives.

By *budding* is meant the formation of small outgrowths from the mother's body which grow into her likeness. They may, or may not, separate from her—if they do not separate they form compound systems known as *colonies*. Budding and colony formation are practically confined to four groups of Metazoa, viz. the Sponges, the Cœlenterata (polyps, sea-anemones, and corals), Polyzoa (sea-mats), and Tunicata (sea-squirts). The Sponges and Cœlenterates are very simply organized animals and lie at the base of the Metazoa; the Polyzoa are much more highly organized but are all small animals of microscopic size, and the colonies formed by them constitute delicate films like lace, which cover the insides of dead shells or the fronds of seaweed; the Tunicata, which externally resemble sponges, are really degenerate Vertebrata—that is, members of the group to which we ourselves belong. The important point to remember is that, whether a group of Metazoa reproduces by fission or budding or not, all Metazoa also produce germ-cells and carry on what is known as *sexual reproduction.*

Germ-cells or *gametes* (Greek γάμος, a wedding) normally require to unite in pairs so as to form compound cells termed *zygotes* (Greek ζυγόν, a yoke) before they can develop. This fusion is the essence of the sex-process, and is termed fertilization. In the simplest Protozoa the gametes which unite are alike, but from the lowest Metazoa up to Man himself the gametes are of two kinds, and these two kinds are of stereotyped forms known respectively as the ovum or egg (female) and the spermatozoon (male). The ovum is a large, rounded, motionless cell, whereas the spermatozoon is a small active organism consisting almost entirely of a *head* which is merely a condensed nucleus and a thin vibratile filament termed the *tail.* In two groups of Metazoa (the higher Crustacea and the threadworms) the power to produce this tail has apparently been lost, but in all others the spermatozoon is of the same essential character, and the spermatozoon of the simple polyp Hydra is not dissimilar from that of Man. The egg varies enormously in size, but this is due entirely to the amount of food material termed *yolk* which is packed away in its protoplasm. The amount of yolk in turn is regulated by the extent to which the young animal must grow before it leaves the egg-shell. A woman has one of the smallest eggs known; it is only 1/125 of an inch in diameter, and is of the same order of size as that of the polyp Hydra. The egg of an ostrich, which is about the size of a cricket-ball, is probably the largest egg produced by any animal living at the present time.

In fertilization the spermatozoon propelled by its tail comes into contact with the surface of the egg and immerses itself in it. The tail has a spiral motion, and this transmits a screw action to the head. As soon as the head is completely plunged into the protoplasm of the egg, this latter secretes a thin flexible membrane, the so-called *vitelline membrane,* which in most cases cuts off the tail of the spermatozoon and in healthy eggs prevents any more spermatozoa from entering [Plate I. (*a*)]. This is the primitive egg-shell. The head swells up by absorbing water from the protoplasm of the egg and takes on the form of an ordinary nucleus; it then moves towards the nucleus of the egg and takes up a position beside it. The essential constituent of every nucleus is a series of gelatinous rods termed *chromosomes* which have the power of absorbing and holding certain stains and thus show themselves to be of slightly different composition from the rest of the protoplasm. Now, even after the so-called union of the two nuclei, the chromosomes of male and female origin can be distinguished from one another. They lie in two clumps, side by side within the protoplasm of the fertilized egg.

The division of the nucleus precedes that of the cell in which it is placed, and the first stage in this division is the splitting of each chromosome lengthwise; one half of each chromosome goes to one pole of the nucleus and the other half to the other pole, and then the nucleus divides across the equator, so that each daughter nucleus contains a half of each one of the original chromosomes of the mother nucleus [Plate I. (*b* and *c*)]. When the egg divides into two cells, this division is preceded by the division of the compound nucleus, which divides in such a way that each cell receives samples of every male and female chromosome that the original egg-nucleus contained. As this process is repeated at every subsequent division up to the complete development of the adult body it is clear that every nucleus in the whole organism contains equal portions of paternal and maternal substance. The nucleus is the real vital centre of the cell. If a simple Protozoan like Amœba be divided into two parts, one with and one without the nucleus, the part without the nucleus will continue moving for a time but is unable to digest or assimilate food and to grow, and, therefore, it soon perishes like an exhausted lamp. The other part behaves in all respects like a normal Amœba of reduced size. So we can understand that although the father only contributes a nucleus to the make-up of the young organism, this nucleus and its progeny exercise a control over the structure and functions of the young animal equal to that exercised by the whole egg. But the spermatozoon has two functions to perform which are quite distinct from one another. One function already described is to imprint the father's image on the young animal, but the other is to wake up the ovum out of the comatose condition in which it is shed from the ovary and force it to begin development. Dr. Isabella Gordon, a brilliant lady zoologist, has described an astounding case where one of these functions may be exercised to the exclusion of the other. There are two sea-urchins to be found near the Marine Biological Station at Wood's Hole, Massachusetts, in America. One of these (Arbacia) is an ordinary sea-urchin shaped like a small apple; the other (Echinarachnius), the so-called sand-dollar, is a flattened form like a large coin. From geology we learn that it is at least 200,000,000 years since these two forms diverged from the same ancestral stock. Yet it is quite possible to fertilize the eggs of Echinarachnius with the sperm of Arbacia, and these eggs will develop, and Miss Gordon has reared them till they became young sea-urchins; but these sea-urchins showed no resemblance to their father Arbacia, but were entirely like the mother Echinarachnius. Other similar cases are known, but in no case have the offspring been reared as far as Miss Gordon has done.

Now, if the spermatozoon has this second function it ought to be possible to wake up the egg by other means, and this problem has also been solved. The eggs of sea-urchins, stimulated by putting them into weak solutions of vinegar and other similar acids and then transferring them to hypertonic (over-salted) sea water, will begin to develop, and with care can be reared into young sea-urchins, a task successfully accomplished by another lady, Dr. Dorothy Jordan Lloyd. Thus an organism of purely maternal origin is obtained, and this procedure is known as artificial *parthenogenesis* (Greek παρθενος, a virgin).

Natural parthenogenesis occurs in certain groups of Metazoa, notably in certain insects, such as green-flies

(Aphis) and in certain Crustacea, such as water-fleas (Daphnia). In both these cases, during summer, no males are to be seen and yet the females go on producing fertile eggs which immediately develop. In all such cases, when winter or other bad conditions set in, males make their appearance and eggs are fertilized—and then lie dormant till better conditions supervene, when they begin vigorous development. It seems, then, that the primary object of fertilization or sexual congress is to mix the powers of two distinct organisms, so that the deficiences of one may be compensated by the excellences of the other. The frequent disastrous effects of the marriage of near relations, such as first cousins—if the family constitution is not strong—are thus accounted for. *The function of sex is not to bring about reproduction but to establish vigour.*

CHAPTER II

THE STAGES OF DEVELOPMENT

If we make a survey of the development of the egg amongst the groups of the Metazoa we find, of course, great differences, but there are certain broad resemblances which such a survey makes surprisingly clear. We can divide the early development of the eggs of all Metazoa into three stages—namely, (1) the segmentation of the egg, (2) the formation of the germinal layers, and (3) Organogeny (*i.e.* the development of special organs).

1. *The Segmentation of the Egg.*—The egg is to start with a rounded cell with a single nucleus; by repeated divisions it becomes converted into a ball of cells and these cells are called *blastomeres*. When the food yolk is very small in amount the egg is said to be *alecithal* (Greek *α* not *λήκυθος*, an oil-bottle). In this case the cells are nearly equal in size and are arranged like a hollow ball round a space called indifferently the *segmentation cavity,* the *blastocœle,* or the *primary body-cavity;* the ball itself is called the *blastula*. Such a simple segmentation is found in the eggs of sea-urchins [Plate I. (*d*)], starfish, polyps, some sponges, and the simplest members of the Vertebrata, such as the lancelet, which is the lowest fish. A lancelet burrows in clean sandy bottoms of seas all over the world and it is usually known as Amphioxus, because, being devoid of skull and brain, it is equally pointed at both ends (Greek *αμφί*, both; *οξύς*, sharp).

In most eggs, however, there is a considerable amount of yolk and this is not evenly distributed through the protoplasm; it is usually concentrated towards one pole of the egg which is termed the *vegetative pole,* whilst the opposite pole, which is relatively free from it, is termed the *animal pole*. Such eggs are called *telolecithal* (Greek *τέλος*, end). The effect of the yolk is to render difficult, and in extreme cases to prevent altogether, the division of that region of the egg into cells: so if we examine the developing eggs of frogs or newts we find that they give rise, indeed, to hollow blastulæ, but these blastulæ at one side have thick masses of relatively few large cells crammed with yolk, whilst at the opposite side we find the blastocœle covered with a roof of a very large number of very small cells. If we examine the egg of the fowl (which is the part colloquially called " the yolk ") we find a very thin slit representing a trace of the segmentation cavity covered with a thin sheet of cells known as the *germinal disc,* whilst all the rest is a vast mass of yolk with a few nuclei, scattered near its upper edge, which represent the abortive attempts of the descendants of the egg nucleus to master the enormous mass of yolk at the vegetative pole. Since, in such cases, segmentation ceases when only part of the egg has been divided into cells, such eggs are termed *meroblastic* (Greek μέρος, part). The eggs of nearly all fish and of all reptiles and birds and the very lowest mammals are meroblastic.

2. *Formation of the Germinal Layers.*—If we examine the further course of development in alecithal eggs, such as those of sea-urchins and of the lancelet, we find that after the blastula stage has been attained another change sets in. One side of the ball of cells becomes pushed inwards, just as if it were indented by an invisible finger, and in this way the ball becomes converted into a two-walled cup with a wide opening [Plate I. (*e*)]. This cup is called the *gastrula* and its opening is the *blastopore.* The outer layer of the cup is called the *ectoderm* and it gives rise to the skin of the young animal, whilst the inner is called the *endoderm,* and from it is produced the lining of the gut and of its outgrowths. These are the first two *germinal*

layers. The whole process is known as *invagination.* What are the forces which bring about this wonderful change? Can we analyze it further? Yes, we can. Close observation shows us that invagination is preceded by a rapid growth and multiplication of the cells of one small area on the wall of the blastula. This produces a lateral pressure, and the blastular wall could yield to this by bending either outwards or inwards. That it bends inwards can only be attributed to an idiosyncrasy of the cells which we may term *inwardly directed cytotaxis.* (Greek κυτος, cell; ταξις, arrangement.) In the case of sea-urchin eggs a slight rise in temperature or the addition of a trace of the metal lithium to the sea water is sufficient to reverse the cytotaxis, and then the endoderm, instead of being tucked inside the blastula, develops inside out as an appendage like a glove-finger attached to the blastular wall.

But now the further question arises, What determines the formation of this area of rapid growth on the blastular wall? Do the divisions of the zygote nucleus, as Weismann imagined, result in daughter nuclei, which, though they appear to be like each other, are really unlike, and is it the peculiar quality of the nuclei in this region that causes endoderm to be formed? Now, Driesch has shown that the blastula of a sea-urchin can be cut into pieces and that any piece of sufficient size will round itself off and form a blastula of reduced size, which then later develops by invagination into a gastrula. Thus we conclude *that all the nuclei are potentially alike,* and that the differences between ectoderm and endoderm are due to differences in the areas of protoplasm of which they are composed.

This is made strikingly clear by the development of the egg of Cynthia, one of the sea-squirts. The egg develops into a small, thick-walled blastula, which then becomes converted into a gastrula in the ordinary way. But the protoplasm that is going to form endoderm can be recognized owing to the peculiar materials embedded in it, which give it a distinctive blue colour; the future ectoderm, on the contrary, remains clear and transparent. Now, at one stage of development a line of cells can be seen on the lip of the blastopore, each of which has, of course, only one nucleus, but in each of which the protoplasm is divided into a blue and a clear area. At the next division each cell divides into two daughters, one blue which is added to the endoderm, and the other clear which joins the ectoderm.

Gastrulation, therefore, consists of (*a*) differentiation of the blastular wall into two kinds of protoplasm, (*b*) increased growth of one kind of protoplasm, (*c*) inwardly directed cytotaxis.

From the endoderm in the simplest eggs there grow out pouches, at first communicating with the cavity of the gastrula, but later cut off from it and wedged in between the endoderm and the ectoderm. The walls of these pouches make up the third germinal layer or *mesoderm*, and the cavities of the pouches are known collectively as the *secondary body-cavity* or *cœlom* (Greek κοιλος, hollow).

By experiments carried out on starfish eggs we can show that the separation of mesoderm from endoderm is also a matter of the segregation of the protoplasm into two kinds. In these animals the gastrula is long and sausage-shaped, and the endoderm is a relatively narrow tube projecting into it from the hinder end and separated from the ectoderm by a wide space, which is a remnant of the primary body-cavity, or blastocœle. The mesoderm makes its appearance as a little bladder-like swelling at the tip of the endoderm [Plate I. (*f*)], which becomes cut off from it and then divides into right and left halves. Now, it is not too difficult a task, and one which Driesch succeeded in performing, to cut off the upper end of the sausage, including the top of the endoderm tube. When this is done the wound heals up and a shorter sausage is formed. This continues to grow, and in due time the curtailed endoderm forms at its tip a bladder and a perfectly normal animal of reduced size results. But if the beheading operation be carried out *after* the bladder is formed at the apex of the endoderm, then, although the sausage will heal up, the endoderm in it will never grow another bladder and no mesoderm will be formed. We conclude, therefore, that up to a certain point in development all the endoderm has the power of forming mesoderm, but that once the bladder has been formed, then all the material capable of forming mesoderm is concentrated in it and the rest of the endoderm loses this power.

It is only in relatively few and primitive animals that the cœlom grows out as a series of pouches. What happens in all the vertebrates except the lancelet is that solid masses of cells grow out from the endoderm, which then become hollowed out so as to form the secondary body-cavity. In the molluscs and worms the mesoderm originates from a single endodermal cell, which becomes pushed out from amongst its fellows into the primary body-cavity and then divides into right and left cells. Each of these then proceeds to bud off a long band of cells, in which still later the secondary body-cavity appears.

3. *Organogeny.*—From these three germinal layers, Ectoderm, Endoderm, and Mesoderm, all the organs of the body are built up. Within the limits of this book it would be utterly impossible to describe the development of the worms, molluscs, shrimps, insects, starfish, sea-urchins, and all the other groups of higher animals. One, however, of these groups, viz. the Vertebrata, consisting of creatures with a jointed backbone and spinal cord above it, is the group to which we ourselves belong, and we shall therefore give a sketch of the way in which the organs of a vertebrate are moulded out of the germinal layers. We propose first to give a short description of the process in the lancelet (Amphioxus), because this animal possesses an alecithal egg uncomplicated by yolk; and then we shall go on to describe the development of the newt, because this is the simplest type of animal which breathes air, lives on land, and supports itself on limbs like our own.

In the case of the lancelet, then, the egg by segmentation forms a simple hollow blastula, which becomes covered with vibratile hairs or *cilia,* and rotates. This blastula is at first spherical, but then becomes flattened on one side so as to take on the form of what may be described as a bowler hat [Plate I. (*g*)]. Then the flat side becomes invaginated and a gastrula is formed, which has a wide blastopore and which therefore may be compared to a thimble [Plate I. (*h*)]. The blastopore is found to correspond to the future hinder end of the little fish. One side of the thimble corresponding to the future back is called *dorsal* (Latin *dorsum*, back), the other side is termed *ventral* and corresponds to the belly (Latin *venter*, belly).

The blastopore, however, becomes narrowed by an upgrowth of its lower lip till it is reduced to a small, round pore at the dorsal side [Plate I. (*i*)]. The mesoderm is formed from (1) a pair of pouches which we shall term the *collar-pouches*, from the upper angles of the endoderm in front, and (2) behind these a pair of outgrowths which we shall call the *cœlomic grooves*, the front ends of which overlap the pouches [Plate I. (*j*)]. When this stage has been reached the first formation of organs begins. One side of the gastrula, which turns out to be the dorsal, becomes flattened, and the cells of this part become taller. This is the *neural plate*, the rudiment of the future central nervous system. Since this is the first organ to make its appearance, the embryo of a vertebrate is often spoken of as a *neurula*. Simultaneously beneath it the middle line of the endoderm becomes arched up so as to form first a groove, and then a rod which becomes separated from the endoderm beginning in front [Plate I. (*k*)]. This rod is the rudiment of the backbone common to all Vertebrata. In the lancelet this backbone takes the form of a gelatinous rod called the *notochord* and in all other Vertebrata it is like this to begin with. In higher Vertebrata it later becomes surrounded by bony rings and forms the well-known jointed backbone of the higher types.

The neural plate sinks in the middle so as to form a groove, and this then is overgrown by two flaps of skin (ectoderm) arising from its sides. These flaps roof over a canal, the *neural canal,* which remains open in front. They extend backwards and cover over the blastopore, so that for a brief space of time the neural canal communicates with the cavity of the endoderm, that is, the gut through the covered-over blastopore. This communication is known as the *neurenteric canal.* Meanwhile the whole embryo grows in length, and the region of greatest growth is just in front of the blastopore. As a result the "cœlomic grooves" become lengthened; the hinder part of each remains in open communication with the gut, but its front part becomes nipped off to form a small vesicle similar to the collar-cavity, which is termed a *somite.* As growth continues a second vesicle is nipped off, and so on; this continues till about fifty somites have been formed on each side. But when about two have been formed the embryo bursts the egg membrane and swims freely about. The *anus* is formed at the hinder end, in that part of the ventral lip of the blastopore which has grown upwards. When the young stage of any animal is hatched, however immature it is, it is no longer spoken of as an embryo, but as a *larva.*

When about five somites have been nipped off from each cœlomic groove, the whole front end of the gut becomes nipped off and forms a bilobed vesicle, which immediately divides into right and left halves, and these are known as the *head-cavities* [Plate I. (*j*) (*m*)]. The left of these remains small and thick-walled and eventually opens by a pore to the exterior (Hatschek's pit). The right expands and grows out in front and so the larva changes its shape and acquires a pointed snout. The neural plate has by this time become bent into the form of a U, and so forms a tube independently of the neural flaps which have met over its crest; it still has an opening in front called the *neuropore*, but at its hinder end the neurenteric canal has become a solid string of cells. Meanwhile great changes take place in the other mesoderm rudiments. The collar-pouches and the somites grow both downwards and upwards, wedging themselves in between the ectoderm and the gut on the one hand, and between the nerve tube and the ectoderm on the other [Plate I. (*l*)]. The lower portions of the collar-pouch and of the succeeding somites are thin-walled; these portions are marked off from the corresponding upper portion by constrictions. The upper portions of the collar-cavities and somites have their inner walls thickened; these thickened walls are transformed into strong longitudinal muscles, by the aid of which the fish moves. They are called *myotomes* and constitute the flesh of the fish. The lower portions join with one another in a fore and aft direction, and thus two large, thin-walled cœlomic spaces flanking the gut are produced. The right space then joins with its fellow beneath the gut and in this way a continuous abdominal cavity known as the *splanchnocœle* is formed. This cavity roughly corresponds to what is usually called the abdominal or peritoneal cavity in Man.

The front portion of the larva behind the head-cavities now swells out; this involves an expansion of the endodermal tube, which thus becomes divisible into a wide pharynx in front and a narrow intestine behind. One side of the pharynx becomes pressed against the skin, and here a perforation takes place which gives rise to the mouth in a totally unexpected place, viz. on the left side. At the same time two short, thick-walled pouches grow out from the pharynx; one is opposite the mouth high up on the right side of the pharynx, the other is just behind the mouth in the mid-ventral line. The right one grows vertically downwards and then forwards and opens below and in front of the mouth; it is called the *club-shaped gland* [Plate I. (*m*)]. The other grows vertically downwards and opens directly to the exterior and is the *first gill-slit.* There is strong reason for believing that the club-shaped gland is the fellow of the first gill-slit, and that its peculiar position, as that of the mouth, is due to a twist which this region of the larva has undergone.

The young larva, which until now has supported itself on the remains of the yolk embedded in its cells, begins to feed. The gill-slit is lined by powerful cilia which suck in water through the mouth. The small organisms contained in this are entangled in a mass of mucus produced by a belt of glandular cells on the right side of the pharynx in front of the club-shaped gland called the *endostyle* [Plate I. (*m*) 13]; they are swallowed whilst the surplus water passes through the gill-slit.

If the larva be not fed at this stage it dies, and consequently it is not possible to rear the eggs in captivity to an older condition than this. The larva in its natural surroundings continues to live for three months, growing in length and adding fresh gill-slits, but not otherwise changing its structure. Then it begins to sink to the bottom and undergoes a rapid metamorphosis which lasts only three weeks, at the end of which time it is a full-fledged Amphioxus.

We may now consider the development of the common English Newt (*Triton cristatus*). This little creature lays its eggs singly and attaches them to the leaves of water plants. The eggs are small, oval, white objects about one-tenth of an inch in diameter. When laid they have already been fertilized, and they are surrounded with an elastic, transparent membrane which is somewhat difficult to dissect off. Although so small, they are giants compared with the eggs of Amphioxus, which are barely one-hundredth of an inch in diameter. The difference in size is due to the greater amount of yolk in the newt's egg, and this yolk is massed towards one pole of the egg, which is termed the vegetative pole. Such eggs are termed telolecithal. The segmentation of the newt's egg is unequal; large blastomeres are produced towards the vegetative pole and much smaller blastomeres towards the yolk-free animal pole. The blastula which results from the segmentation is a hollow ball, but the floor of the blastocœle is formed of a thick pad of yolky cells, whereas the roof consists of much smaller cells with much less yolk. The blastula is then converted into a gastrula, and we are able to recognize the same forces at work as we detected in Amphioxus, though much impeded by the greater quantity of yolk. An area of rapid growth and multiplication of cells appears on one side of the egg. This area appears in surface view as a curved line and afterwards becomes the upper lip of the blastopore. Here cells of two kinds are produced—one sort being added to the small cells forming the roof of the blastocœle, the others streaming into the interior of the egg and nearly filling up the blastocœle and dragging behind them some of the large, yolky cells immediately below them. The ingrowth is at first solid, but soon a cavity appears in it, which is the cavity of the primitive gut, or, as it is conveniently termed, the *archenteron* [Plate II. (*n*)] (Greek αρχαῖος, original; εντερον, intestine). This cavity opens by a slit just beneath the curved line of greater growth, and this slit is, of course, the beginning of the blastopore.

If we now follow the small cells forming the roof of the blastula over to the other side of the egg, we find that they at first pass by insensible gradations into the large cells of the vegetative pole. After, however, the first steps in gastrulation have been accomplished, we find that on this side of the egg also the small cells of the roof are separated from the large cells below by a curved line of growth and differentiation, which afterwards corresponds to the lower or ventral lip of the blastopore. Here, owing to the size of the yolky cells, there is no room for instreaming; the small cells appear to creep over the larger cells. Such creeping is called *epiboly*. The curved lines representing the upper and lower lips of the blastopore become joined, thus outlining a large circular opening filled by a plug of large yolky cells. This opening gradually narrows—the lower lip grows up and the lateral lips grow in from the sides, and thus it is reduced to a comparatively small pore. It is obvious that in this process we have the same thing as the upgrowth of the ventral lip in Amphioxus. The formation of the mesoderm is likewise affected by the yolk in the cells. The equivalents of the head-cavities and of the collar-pouches are budded from the endoderm as solid masses of cells, which afterwards become hollow; the cœlomic grooves are also represented by solid ridges of cells, and the notochord is formed as a solid rod of cells, not as a groove in the endoderm. But it is to be noted that in the newt (and the same is true for all other higher Vertebrata) there is no trace of the skewness or want of symmetry which we detected in the front region of the embryo of Amphioxus. The head-cavities, right and left, are of precisely the same size.

The neural plate is formed as in Amphioxus, but it is several cells thick, and the same is true of the neural flaps, which in the higher Vertebrata are known as the *medullary* folds. These folds, as in Amphioxus, extend behind the neural plate into the region of the blastopore, and eventually meet over part of it and cover it in, thus giving rise to a neurenteric canal, *but they leave the lower part of the blastopore uncovered, and this uncovered portion becomes the anus of the little newt* [Plate II. (*q*)]. Thus the covering up of the entire blastopore in Amphioxus and the reopening of the anus in what was its ventral lip is apparently a secondary state of affairs produced by the rapid upgrowth of this lip; the original form of development so far as the blastopore is concerned appears to be that found in the newt. The neural plate of the newt has an expanded portion in front, which is not found in Amphioxus. This portion is the rudiment of the brain, and when it is covered in by the medullary folds it forms a large bladder, which is almost immediately marked out by constrictions into three bladders, one behind the other. These bladders are the rudiments of the *fore, mid,* and *hind* brain. From their walls the brain-cells are formed, and their cavities are the so-called ventricles of the brain.

Once the brain is formed the beginnings of the segmentation of the mesoderm and of the formation of the mouth and gill-slits can be observed. The mesoderm bands, which correspond to the cœlomic grooves of amphioxus, do not become completely divided into somites; only their upper portions become segmented; these portions are the rudiments of the myotomes, whilst the lower unsegmented portion splits so as to form the splanchnocœle. The place where the mouth will break through is indicated by a shallow pit in the ectoderm, *and this pit is exactly* *in the middle line;* it is not on the left side as in Amphioxus. The gill-slits originate as pairs of folds of the front enlarged part of the gut, *i.e.* the pharynx, situated exactly opposite each other; there is no skewness such as we observed in Amphioxus. There are six pairs of these folds; at this period the limbs of each fold are in contact with one another, not opening out into slits till a much later period of development. They decrease in size from the front backwards, and at the same time the members of each pair approach one another. The hindermost and shortest pair never open to the exterior, and are the rudiments of the lungs.

The Craniata or Higher Vertebrata differ from the Acrania, of which the type is Amphioxus, not only in possessing a brain, but in having eyes, ears, and nose. It is probable that the eyes, ears, and nose have brought about the development of the brain, which is nothing but an enlarged portion of the spinal cord arranged to receive and co-ordinate the sensations from these sense-organs.

The newt embryo shows the beginnings of all three senses. The eyes arise as side-pouches of the fore brain, the ears and nose as little shallow pits of thickened ectoderm. The pouch of the brain gives rise to the *retina* or sensitive portion of the eye; the lens is derived from a little shallow pit of skin similar to those which give rise to the ears and nose. Before the embryo bursts the egg membrane, the beginnings of peculiar newt organs appear; these are the tail and the external gills.

The *tail* is a portion of the body behind the anus; its primary use is to serve as a stern oar to propel the animal through the water, and so it is most developed in fish, in which it may be several times longer than the rest of the body. It begins in the newt as a bud of young, actively growing cells situated just where the neurenteric canal used to be—in fact, it might be said to be produced by the transformation of the cord of cells into which that canal degenerates. By the activity of this bud new portions of all three germinal layers are formed behind the anus; a new portion of the spinal cord; a new portion of the notochord; and a new set of myotomes.

The external gills are feather-shaped outgrowths of the ectoderm on each side, situated just above the spots where the second, third, and fourth gill-pouches will break through; they allow the young newt larva to get its oxygen from the air dissolved in the water before its gill-pouches are open. When this stage is reached the embryo breaks out of the egg membrane and becomes a newt larva [Plate II. (*o*)]; it lives in the water as a fish for three months before it comes out on dry land and begins to lead its ordinary life as a newt.

The interest in the development of the newt is not merely that it is the lowest animal whose body may be regarded as a rough sketch of the human frame, but that the embryos and larvæ of the newt have been for the last thirty years the subject of the most wonderful experiments, which have thrown a flood of light on the forces which are at work in building up the animal's body. As similar experiments have also been done on the tadpole of the frog, we may glance at the points wherein the frog's development differs from that of the newt. The embryonic development of the frog differs from that of the newt in such trifling details that they need not be noticed here. But the larva, the ordinary tadpole, has certain peculiarities of its own. Both tadpole and newt larva when hatched have three external gills on each side; the newt larva has, in addition, a pair of rods called *balancers* hanging from each side of the lower jaw which are not gills, and the use of which is not known. Both types of larva have a flap of skin called the *gill-cover,* which grows out from behind the first gill-pouch and tends to grow over the gills. In the newt, however, it remains slightly developed, and the newt larva retains its external gills throughout the whole of its aquatic existence, and they are the principal organs of respiration. The fore limbs appear as tiny buds before the hind limbs can be seen, and they develop at first two fingers only. In the frog, on the other hand, the gill-cover develops rapidly and grows over the gills, completely fusing with the body wall beyond them. The gills thus become closed in a space known as the *branchial chamber,* and they shrivel up and drop off. The right and left branchial chambers open into each other below, and the left opens to the exterior by an aperture called the *spiracle.* Small tags develop from the edges of the now open gill-slits; these are the so-called *internal gills,* and they serve as breathing organs for the rest of the larval life.

When the buds of the fore limbs are formed they grow into the branchial chamber and are invisible from the outside. The hind limbs appear at the same time as the fore limbs. When the tadpole leaves the water it thrusts its arms through the covering of the branchial chamber, and then for a day or two it resembles a newt which has just left the water. But the newt keeps its long tail throughout life, only losing the fin which runs along it, whereas, as everyone knows, the frog loses its tail entirely.

CHAPTER III

EXPERIMENTS ON THE EGGS AND EMBRYOS OF AMPHIBIA

The principal people who have performed experiments on Amphibian eggs, embryos, and larvæ are Roux, Hertwig, Schulze, Brachet, Spemann, Lewis, and Harrison. To give any complete account of the work of these scientists would fill several large volumes; we can only mention briefly the most striking experiments performed by each of these investigators.

Roux took the frog's egg when it had divided into two and killed one cell with a red-hot needle. The remaining cell developed into a half blastula and then a half gastrula. Sometimes this half gastrula survived, and then by the division of its nuclei and the budding-off small cells it regenerated the complete embryo and became a normal tadpole. Hertwig followed Roux and denied the accuracy of his work: he maintained that the surviving cell always strove to form a complete embryo and only failed in its attempt owing to the obstruction to its growth caused by the body of its dead sister.

Brachet showed that both these experimenters were right; he proved that when the spermatozoon penetrated the egg it left behind it a track of pigmented material which determined the future axis of symmetry of the egg and the plane of division separating the first two cells of the egg sometimes coincided with this axis. When it did so, each of the first two cells, if separated from the other, gave rise to a half embryo, but when the plane of division was oblique to this axis each cell tended to grow into a whole embryo. From these experiments we draw the conclusion—already arrived at from experiments on sea-urchin eggs—that it is not differences between the nuclei which determine which parts of the egg shall grow into different organs of the body, but different sorts of protoplasm; but now we learn that these different kinds of protoplasm acquire their typical arrangement under the influence of the entering spermatozoon. We owe a still more startling observation to Brachet. He has observed a case where one frog's egg was entered by seven spermatozoa. *One* of the spermatozoa traversed the egg and joined the egg nucleus forming the zygote nucleus—the others remained scattered in various parts of the egg. All, however, divided and compelled the division of the protoplasm round them into cells—but the size of the cell depended on the size of the nucleus; and thus the cells surrounding the daughters of the zygote nucleus were double the size of the cells surrounding the daughters of the extra spermatozoa. *Yet from this medley of cells there resulted, not a monster but a normal tadpole,* some parts of whose body were composed of smaller cells than others.

Schulze performed the striking experiment of clamping the two-cell stage of a frog's egg between two glass plates and then inverting the preparation and allowing it to develop in clean water for five or six days. This experiment (which we have repeated) results in the formation of a tadpole with two heads or two tails. Here nothing has been added or taken away, only the relative positions of the various materials in each cell have been altered by gravity, and so each cell is diverted from its normal task of forming a half embryo and forms instead a whole one.

Spemann's experiments are the most wonderful of all, and extend over a period of at least twenty-five years. He began by showing that if the gastrula of a newt be slightly constricted in the median plane by drawing a silk thread around it, it produces a larva with two heads—so that we conclude that the outline of the embryo in this stage determines whether it is to develop into two beasts or one.

There are in Central Germany, where Spemann worked, several species of newt: one of these allied to our own British newt has, like it, a white egg; another species has a brown one. Spemann reared both kinds of egg side by side till they had reached the stage of the early gastrula. Then with a fine needle he removed a small portion of the upper lip of the blastopore from the white egg and inserted it in the flank of the gastrula produced by the brown egg. The white tissue flourished in its new situation and retained its colour, so that it could be recognized throughout development. *It entirely altered the fate of the brown cells around it.* These cells would normally be incorporated in the flank and belly of the brown embryo; instead of which they formed a new neural plate which was duly converted into a spinal cord and brain, and the endoderm cells of the layer beneath them formed a notochord—entirely irrespective of the fact that the normal spinal cord and notochord of the embryo were formed in their usual position! [Plate II. (*p*)].

Lewis experimented with the tadpole of a frog. Choosing a very young stage, where the retina of the eye appears as a stud on the side of the fore-brain, he slit open the skin of the back, cut off the retina on one side from the brain and pushed it back under skin as far as the shoulder. He then laid the flaps of severed skin in contact and attached them to one another with a little white of egg. Healing soon took place, and the tadpole resumed its interrupted life and growth. The displaced retina in its new situation found itself immersed in a blood-stream; it grew, *and it compelled the skin of the shoulder opposite it to form a lens.*

Harrison removed from the side of a young newt embryo the bud which would give rise to the fore limb, and he grafted this bud in various situations on the flank of the same or of another embryo. Here it grew into a limb, and it was possible in this way to insert a limb much farther back than its normal position. Harrison's pupil Detweiler showed that, under these circumstances, the nerve which should have supplied the limb grew out from the spinal cord and followed this displaced limb to its new position. But if the limb were displaced too far backwards, then another spinal nerve issuing from the nerve cord farther back grew into the rudiment of the developing limb and supplied its muscles, although in the normal case this nerve would have borne no relation to the limb whatever.

If we sum up the conclusions that may be fairly drawn from this wonderful series of experiments, they seem to be as follows:

1. The egg before fertilization contains various kinds of materials in its protoplasm, different proportions of which are necessary for the construction of the primordial organs, that is, the primary germinal layers. The definite arrangement of these materials, which results in the establishment of the primary axis of the future animal, seems to be due to the path pursued by the sperm nucleus in its passage from the vegetative pole upwards till it meets with the egg nucleus and forms the zygote nucleus.

2. The nuclei formed by the division of the zygote nucleus seem to be equivalent to one another, so that each possesses all the powers necessary to produce the whole organism—which of these powers will be developed, however, depends on the situation in which the nucleus finds itself. In the frog's egg, for instance, the zygote nucleus normally gives rise to all the cells of the animal, but when there are additional sperma-

tozoa present it only produces the cells of a part; other cells are produced by the extra spermatozoa; but all the cells, however produced, are moulded into one normal animal.

We may pause to remark how impossible it is to explain this action of the nucleus by any "mechanical" hypothesis. If, for instance, two nuclei were exercising competing influences of a physico-chemical nature on the same protoplasm we should expect the consequence to be that a *resultant* of these two influences would be produced, but that is not what occurs; the work of one is subordinated to the work of the other, and the two are co-ordinated into a harmonious whole.

3. So far we have been mainly discussing the primitive organs, or the germinal layers, but when we study the development of the more specialized organs we learn that when once one kind of organ is formed it will work on neighbouring undifferentiated tissue, whether this be ectoderm or endoderm, so as to alter the fate of this. The organs which exercise this control are of nervous origin. Thus the retina, which is a lobe of the fore-brain, compels the skin near it to form a lens. The upper lip of the blastopore, which includes the vigorous growing end of the spinal cord, when implanted in the ectoderm of another species, transforms the tissues near it into a spinal cord.

Now it is abundantly proved that the nucleus controls the assimilation of food and, consequently, the growth of the cell. Therefore, we are justified in regarding all the varied kinds of growth exhibited in development as powers inherent in the nucleus, and, as we have reason for regarding all nuclei as equivalent to one another, we must regard these powers as present in all the nuclei of the body wherever situated. These powers may conveniently be termed *memories,* and correspond to what in human life is termed habit-memory. What part of these memories will come into play depends on surrounding circumstances. It was because of the utter impossibility of constructing any scheme, mechanical or chemical, which would explain this purposeful and partial development of memories that Driesch advanced his theory of the *entelechy,* or indwelling " spirit " which directed the growth activities of an embryo towards a predestined end. For instance, the skin of a tadpole's shoulder has never in the history of the race produced anything like a lens, and cannot have in it the material necessary for one; but it is able to produce these materials when, by the intervention of the experimenter, it comes into contact with a retina.

CHAPTER IV

EMBRYOS AND LARVÆ

We have seen that the eggs of the lancelet, newt, and frog begin their development inside an egg membrane, and whilst thus enclosed live at the expense of food material embedded in their protoplasm. During this period they are termed *embryos,* but sooner or later they burst the membrane and lead a free existence, although they are still very unlike the full-grown animal, and in this stage they are termed *larvæ*. When first they are set free they still have a reserve of yolk to support them, but very soon they learn to get their own food. During the change from water to land life they cease to feed, and, as those who rear them know well, unless they have been previously well fed they die during the act of metamorphosis. Now, a critical survey of the life histories of animals in general reveals the fact that in all development there is first an embryonic and then a larval phase, but that these two are not always of the same relative length. For every egg begins to develop inside an egg membrane; none is ever thrust out naked into the world, and, however large and well provided with yolk the egg may be, no animal is ever hatched exactly like the parent—in every case the parental form is only reached after a period of free growth in the open. To confine the term larva to cases like that of the frog, where the young one differs widely in habits and appearance from the adult, is to draw an arbitrary line of division. The human baby, and even the small child, is a larva as truly as is the tadpole.

The first well-marked stage in development is the blastula; this is a larva in the life history of polyps, some sponges, starfish, and sea-urchins; in these cases the larval phase is enormously longer than the embryonic one. Broadly speaking, the more developed the animal is from the point of structure, the longer is the embryonic phase; but to this statement there are many sporadic exceptions. Thus, in some starfish yolky eggs are produced, from which the animal hatches in an advanced state of development and, after a sluggish larval life, in which it keeps near its mother, it metamorphoses into a young starfish. The causes of these casual lengthenings of the embryonic phase are usually to be found in some peculiarity of the environment of the particular species, which make the outer world very unhealthy for young larvæ.

Such circumstances render it very probable that the larval phase is the primary mode of development and the embryonic phase a modification and improvement of it; and this probability rises to a practical certainty when we consider certain cases among the Amphibia (frogs and newts) which have been already discussed in our volume of this series dealing with *Evolution.* We may remind our readers of one of these cases here. There lives a species of Amphibia in Central Europe which is closely allied to the newt, but larger and even better adapted to land life than is the newt. This is the salamander. The newt, as we have seen, lays eggs, but the fire-salamander (*Salamandra maculosa*) brings forth her young already equipped with four limbs and external gills. The newt enters the water, but the salamander stands at the edge to give birth to her young, and if she falls into the water she is drowned. The young live in the water for about six months before losing their gills, closing their gill-slits and coming on land.

Now, there is another closely allied species of salamander (*S. atra*) which inhabits the high Alpine meadows where the ponds have ice floating upon them till June. This salamander, instead of producing thirty or forty young at a birth, like its relative, brings forth only two, but these two resemble the parent in most points and never go into the water at all, but at once take up land life. If we open the body of a pregnant *Salamander atra,* we find that she has a right and a left womb, and in each womb are five or six embryos. Only those embryos situated farthest back undergo a complete development; the others degenerate and serve as pabulum for their lucky sisters. These fortunate ones, whilst in their mother's womb, have long external gills, which are absorbed before they are born. A lady experimenter proved that if at this stage the embryos were cut out of the mother's womb they were capable of living in water like ordinary newt larvæ, provided sufficient care was taken to protect them from moulds and bacteria. No naturalist has seriously doubted that in this case at least the embryonic phase is a transformed larval one, and it is a reasonable deduction that the same explanation will be valid in all cases of an embryonic phase.

But what is the larval phase itself? In the volume on *Evolution* we gave reasons for believing that it was a memory—shortened and often much blurred—of a past condition of the race. We often find that there are large groups of animals, consisting of many families, genera, and species, throughout which one uniform type of habits and corresponding structure prevails. Included in these groups, however, are exceptional genera with peculiar habits; these genera have often life histories with a long larval phase, and in these cases the larva shows the typical habits and structure of the large group to which the adult belongs. Thus, the shipworm is an extraordinarily distorted clam which burrows in wood, but when young it resembles the ordinary clam (*Mya*), which burrows in mud. The Anomura are a group of crabs which protect the abdomen by thrusting it into the empty shell of a whelk or other sea-snail. In consequence the abdomen is spirally curved and appendages are only developed along one side. But the young of these Anomura are small, shrimp-like creatures in which the abdomen is perfectly symmetrical, with appendages developed equally on both sides. Now, no naturalist doubts that the shipworm was evolved from a clam-like ancestor and that the Anomuran is descended from an ordinary shrimp; so that in these cases the ancestor may be said to be independently known, and if we find that the larva really resembles this ancestor, then we feel justified in concluding that the larva is always a memory of an ancestor, even where we have no other evidence of such an ancestor. If, as we have seen, embryonic phases are nothing but modified larval phases, then they, too, have an ancestral significance, and so we are led step by step back to the blastula, and, since this stage occurs in all the life histories of the Metazoa and is, as we have seen, a larval phase in the development of the simplest animals, we arrive at the startling conclusion that all the various tribes of Metazoa, however different from one another they now appear to be, are ultimately descended from the same stock of simple blastula-like ancestors. But the ovum itself is a simple cell on the same level of organization as one of the smaller Protozoa, and compound Protozoa are known, such as the green Volvox of our ditches, which is a rolling, ciliated ball of cells; it is, in fact, permanent blastula. It follows that in every type of life history we have a rapid *recapitulation* of the whole story of that particular race from its beginning in the Protozoa till the present day. This interpretation of development was first put forward by Haeckel in 1866, and it is known as the "*theory of recapitulation.*" We regard it as one of the greatest achievements of biological science; it lends a fascinating interest to the study of embryology, and is, as we have indicated in the volume on *Evolution*, our only source of knowledge of the ancestral history of Man. It has been bitterly attacked, but in our judgment the progress of embryology makes its truth ever more evident. Even those naturalists who have criticized it have assumed its truth in their reasonings about the affinities of animals, a proceeding which reminds us of the saying attributed to Brahma: "When me they fly I am the wings."

Of course, Haeckel and all who have followed his views recognize freely that the recapitulatory record is not only abbreviated and blurred by the leaving out of ancestral structures, but also falsified by the development of special larval structures which were never present in the ancestor, but which are adapted to enable the larvæ to meet their present difficulties. But since the life history of every species is a special edition of this record, it is possible by comparing editions to eliminate what is secondary, and to sketch, at least in outline, what is primary, just as an historian by comparing together various documents can make a probable guess at the actual course of events. We may add that, as our knowledge of fossils increases, the deductions from embryology often receive startling confirmation; peculiarities of embryos which we had been inclined to regard as secondary modifications turn out to be memories of former ancestral conditions. Of these confirmations we may mention one instance. In the development of the skull of the Mammalia (the group to which we belong) it always was a puzzle to find the hammer-bone of the ear (the malleus) developing from the cartilage, which in the embryo represents the lower jaw. But now a whole series of skeletons have been found in South Africa which turn out to be the forerunners of mammals. In these skeletons the lower jaw, as in reptiles, is composed of a series of bones, and we can trace the gradual diminution in size of the hindermost of these bones till it becomes converted into the malleus of the ear.

But now the question arises, Why should the younger stages of the life-history be memories of ancestral conditions? The only answer that we can make to this question is that evolution took place because animals changed their habits in response to the needs imposed by a new environment, that these new habits were assumed only after the animal had grown to a certain size, and that in younger stages of growth it continued the ancestral habits. As time went on the new habits were assumed at progressively younger stages of growth. Another way of stating this is to say that the larva becomes progressively smaller in size.

Eimer, one of the greatest evolutionists of last century, laid down the rule that new characters appear first in the males and at the end of development. At the present day the Gorilla is learning to walk on the ground. The old males have ceased to climb trees, but the females and young are sent up the trees every night for shelter. Still the question presses, how did the new habits become engrained in the constitution of the animal? In the volume on *Evolution* we have brought forward evidence to show that, as a matter of fact, new habits do make an impress on the constitution. As to "how" it is done we can only hazard conjectures, and purely in this spirit the following guess is put forward:

The nucleus is the centre of the life of the cell. It restores the waste of the cell after the exercise of any function, but this waste is not general but specific, according to the nature of the function. The nucleus exercises its power by emitting materials into the protoplasm; sometimes these can be detected by special stains. These materials must be replaced, and if we assume that a strong exercise of function leads to a strong replacement of such materials, then the nuclei will be loaded with an excess of the particular kind of material which will be given off into the blood and be absorbed by other nuclei—especially by the nuclei of the germ-cells which, before development, are not wasting away by the exercise of any function. The germ-cells, when they give rise to the next generation, will pass on to the nuclei of that generation an excess of a particular substance. The next generation, exposed to the same stimuli as their immediate parents, will therefore respond more quickly to it and with a greater intensity of reaction than did their parents, and this will lead to a further accumulation of the substance. Finally, so much of this substance will be stored in the nuclei that the reaction which formerly required the stimulus of the activity of the animal to call it forth, now begins without that aid, as when the baby's eye develops in the darkness of the mother's womb.

We have, as a matter of fact, definite proof that the germ-cells emit into the blood materials which influence the growth and appearance of the parent who holds them; thus Zawadovsky has shown that if the ovary be removed from a hen and the testicle of a cock be implanted in the castrated bird, it will assume the feathering, the comb, wattles, spurs, and voice of a cock. It is reasonable to suppose that other organs of the body emit materials into the blood and that they can be absorbed by the germ-cells, and these materials may be regarded as the physical correlates of *memories*. Thus in the germ-cells and in the embryonic cells derived from their division there would be laid up layers of memories, and development would consist in the activating of these in their proper order. There is a striking similarity between this view of development and the conception of the human mind which has been formed by modern psychologists. They regard the mind as made of layers of memories—the lower ones being termed "suppressed complexes." Two wonderful examples of suppressed complexes in animal development may be mentioned here. The common newt, as we have seen, spends the first six months of its life in water and then migrates on land and requires four years to become fully adult. But some species of newt find water life more profitable in their pecular situations, and remain in the water till they develop their germ-cells and lay eggs; they never lose their gills and gill-slits or come on land at all. Such a newt is the Axolotl, whose original home is in the lakes of the Mexican Plateau, 7,000 feet above the sea. This newt is now imported in large numbers into this country and readily breeds in captivity. Yet, as a lady experimenter (Mdlle. Chauvin) first showed in the Jardin des Plantes of Paris, if axolotls are tempted by baits of food to come on land they will gradually lose their gills, close up their gill-slits, lose the fin-fold on their tails, and turn into ordinary newts of the American genus Amblystoma. The same result can be attained even more quickly by feeding them with thyroid gland. The Olm (Proteus) is another newt which never leaves the water and retains its gills and gill-slits throughout life; its home is in the cave-pools of Carnithia in Austria, where light never penetrates. Consequently not only is the skin of a pale corpse-like colour, totally devoid of pigment, but this newt is completely blind, the only remnant of an eye being a little ball of pigmented cells buried deep beneath the skin. If this newt be brought into the daylight the skin forms pigment but the eye does not develop; if, however, the animal is kept in the dark, but exposed at regular intervals to the ruby light of the photographic dark-room, then the pigmented ball of cells develops into a fully formed eye which can be proved to have acquired the full power of vision.

The reader may perhaps ask whether this view of development is not at variance with the facts which point to the conclusion that the differentiation of the primary organs is the consequence of the accumulation of different protoplasmic substances in definite positions, whereas all the nuclei of the embryo are potentially alike. But these substances themselves are the results of the activities of the nucleus. In the very young egg none of the inclusions of the larger and riper egg are visible. In the older eggs of the thread-worms, for instance, definite regions of protoplasm necessary for the formation of distinct organs can be demonstrated before development begins; in the younger eggs it is possible to shear away large parts of the protoplasm by centrifugal force, yet the course of development is quite unaffected by such losses. This shows that at this stage all portions of the protoplasm are alike in power. *We are thus led to the conception of an intermittent action of the nuclei on the protoplasm, an action which initiates all the new starts in the course of development.*

CHAPTER V

THE DEVELOPMENT OF YOLKY EGGS

In discussing the view that development consists of a series of memories of the past history of the race, we stated that these memories may become blurred and distorted by secondary influences and that the history of the race can only be elucidated by comparing together many developments. It would be entirely outside the compass of this book to discuss all the influences that modify development, but there is one which acts powerfully in changing the development of the most familiar animals, and to this we may devote some attention. This influence is yolk, and we have already seen (p. 17) that when yolk is accumulated in protoplasm it slows down the formation of cells and brings it about that a few large, clumsy cells are produced, and that folding processes become impossible. When the yolk exceeds a certain amount, all cell division stops, and the vegetative pole of the egg becomes a mass of yolk spherules strung on a loose network of protoplasm with a few nuclei—the result of abortive attempts at cell division scattered on the upper surface. The animal pole, consisting of a small disc of protoplasm relatively free from yolk, which is termed the *germinal disc*, divides quickly into cells, and the various stages of development described in previous chapters rapidly supervene, whilst the great mass of yolk remains as an inert appendage known as the *yolk-sac*, so that in the development of the cuttle-fish, for instance, we have the ludicrous appearance of a tiny squid stuck on the surface of a ball of yolk. Eggs of this type, known as *meroblastic,* are found in the cuttlefish, in sharks and rays, in reptiles, and finally in birds.

A brief sketch of the early development of our common dogfish may now be given in order to illustrate this type of life-history. The dogfish (*Scyliorhinus canicula*) is the smallest species of shark. The egg is the size of a large bean, and as it passes down the egg-tube (oviduct) of the mother it is first fertilized by spermatozoa which she has received from a male and which are ascending the oviduct, and then it is surrounded by a horny egg-shell shaped like a pillow called the *egg-purse.* The corners of the pillow are drawn out into elastic cords which, when the egg is laid, curl themselves round fronds of seaweed, and so the purse remains ("rocked in the cradle of the deep") for about nine months, till the young shark bites its way through and escapes ready to take up its predatory life. In the aquarium of the London Zoological Society these shark purses may be studied living and the motions of the baby within discerned.

Many spermatozoa normally enter this large egg—one unites with the female nucleus, the rest remain dispersed in the protoplasm. All start cell division, but the cells formed round the daughters of the zygote nucleus are so much more vigorous than those formed by the daughters of the extra spermatozoa, that these latter are crushed and killed; they are not incorporated in the body of the embryo, as is the case with the many spermed egg of the frog.

The germinal disc is soon completely changed into cells. Those above are firm and columnar, but at the sides they become irregular and filled with yolk spherules and, finally, are succeeded by undivided protoplasm crammed with yolk with some nuclei scattered through it. Between these upper cells and the irregular cells of scattered nuclei below an irregular cavity makes its appearance; this is the blastocœle, or primary body-cavity. The germinal disc slopes very gradually into the yolk in front, but its hinder slope is steeper and here a curved lip makes its appearance. This is the dorsal lip of the blastopore—it is exactly the same as the corresponding structure in the eggs of Amphioxus and the newt—and here an active centre of growth and differentation of cells is formed, and the germinal layers begin to make their appearance. An ingrowth of cells takes place beneath the lip, and between this ingrowth and the yolk with nuclei below a cleft appears, which is the rudiment of the primitive gut or archenteron [Plate II. (*t*)]. From the mid-dorsal wall of this gut a rod of cells is folded off, which is the rudiment of the notochord; from its upper angle folds of cells grow out which correspond to the cœlomic grooves. The head-cavities and collar-pouches are formed later from the extreme front end of the archenteron, whilst on the dorsal surface in front of the blastopore an unmistakable neural plate is laid down, at the sides of which medullary folds make their appearance. In a word, the formation of the germinal layers and the earliest steps in the growth of organs, apart from details, is the same as in the newt.

But on the vegetation side of the egg matters are very different. Here we note two processes going on simultaneously which really belong to different stages of development. The nuclei in the yolk mass, which represent unsuccessful attempts at dividing it into cells, rise to the surface, and round them are cut off gradually thin plate-like cells. In this way a skin of flattened endoderm cells gradually grows over the yolk and ultimately completely encloses it. Such a skin is known as a *blastoderm*. The formation of this skin is obviously a delayed segmentation of the vegetative pole. A little later than the beginning or the formation of this skin the upper cells of the germinal disc start to grow over the yolk and over the skin of endoderm. This process obviously corresponds to the upgrowth of the ventral lip of the blastopore in Amphioxus, and to the "epiboly," or overgrowth of the large cells in the newt's blastula by the smaller cells. In this way a skin of ectoderm sweeps over the egg, advancing from the edge of the germinal disc to the lower pole and then coming in from right and left sides on the posterior aspect. These two sides leave open between them for a time a space that is called the *yolk blastopore* [Plate II. (*r*)]. This opening is connected by a seam with the opening under the dorsal lip of the blastopore and obviously represents the lower part of the great thimble opening of the gastrula of Amphioxus. Eventually, this yolk blastopore becomes closed and the seam obliterated. Long before this time, however, the neural plate has become moulded into spinal cord and brain; and rudiments of nose, eyes, and ears have been laid down; the tail begins to grow out whilst the neurenteric canal is still open, so that this canal becomes pulled out into the form of a U [Plate II. (*u*)].

The heart arises as a space on the front aspect of the germinal disc in front of the yolk-sac. It is enclosed between the two front ends of the down-growths from the lateral plates of mesoderm (= mesoderm of the cœlomic grooves in Amphioxus). These mesodermal plates form its muscular walls. Other irregular spaces in the wall of the yolk-sac between endoderm and ectoderm form a network of vessels which open into it. Once the heart and vessels are formed the yolk in the interior of the yolk-sac begins to be digested, and the products diffuse into the blood-vessels and are carried away to parts of the embryonic body and help to nourish them. As a consequence, the yolk-sac grows smaller and the embryonic body which corresponds to the original germinal disc grows larger. This "body" becomes marked off from the yolk-sac by anterior and lateral folds, so that the head projects freely above the yolk, whilst, posteriorly, the tail projects as a free appendage. Ultimately, the yolk-sac becomes so much reduced in size that it forms an inconspicuous wrinkle on the abdominal wall, which is later smoothed out and the dogfish is hatched. We see, then, that the main effect of the yolk is to hold back the development of the vegetative pole of the egg, whilst that of the animal pole races on.

We now turn to the development of the hen. In this case, also, the egg is fertilized whilst in the oviduct of the mother, and is later surrounded by the white of the egg, which is a milky fluid secreted by the oviduct, and then by the well-known shell. The egg itself is the so-called "yolk," and the future axis of the embryo lies across the axis of the egg-shell.

The extra spermatozoa enter the egg just as in the case of the dogfish, and the cells produced by them are crushed out by the growth of cells produced by the zygote nucleus. There is a small germinal disc, the lower cells of which pass first into large yolky cells and then into unsegmented protoplasm with free nuclei. But when development begins a number of important differences from the dogfish can be noted. These include the spreading of ectoderm over the yolk —in a word, the formation of the ventral and lateral lips of the blastopore begins *before* the formation of the dorsal lip. This ectodermic skin, or "blastoderm," before it has spread more than a little way towards the vegetative pole, sweeps round laterally and encloses the original germinal disc in the ring. The germinal disc is known as the *area pellucida,* because the blastocœle is formed beneath it, and it, therefore, appears semitransparent. The lateral lips of the "yolk blastopore," meeting behind it, define an area known as the *area opaca,* because beneath the skin of spreading ectoderm large yolky opaque endoderm cells are being cut out of the yolk by the action of the scattered nuclei [Plate II. (*s*)]. Then the dorsal lip of the blastopore is formed—this takes the form of an elongated indentation known as the *primitive groove.* Owing to the premature union of the lateral lips of the yolk blastopore this groove conveys the impression of originating inside the germinal disc and not, as it should, at its edge, where it actually does arise in the dogfish.

From the primitive groove a great ingrowth of cells takes place which penetrates beneath the area pellucida, or germinal disc. This ingrowth, as it passes forwards, becomes divided into an axial rod in the centre and two masses of cells, one at each side. The axial rod of cells is the notochord; the mass at each side represents the cœlomic groove of Amphioxus, and is the rudiment of the mesoderm. But in the dogfish the notochord and mesodermal rudiments are pinched off from the walls of a primitive gut or archenteron. What has become of this sac in the chick? In the dogfish the floor of the archenteron is unsegmented yolk. Now, if we turn to the development of a primitive lizard like the gecko, we find that the dorsal edge of the blastopore (the primitive groove) does lead into a tube lined with more or less flattened cells. Beneath the floor of this tube a cavity is formed by the separation of endoderm cells from the yolk. Then the roof of this cavity and the floor of the invagination cavity fuse together and are absorbed. From the roof of the conjoined cavities, then, the mesoderm is cut off as a deep fold at either side, and the notochord is formed as an axial rod in the middle. It is obvious that the solid ingrowth of cells from the primitive groove in the chick corresponds to the hollow invagination in the gecko; this is termed the primary endoderm. It is further clear that the cavity of the primitive gut (archenteron) is formed partly by invagination, and partly by splitting of endoderm cells from the yolk; these latter are termed the secondary endoderm.

Once notochord and mesoderm are formed events proceed exactly in the same way as in the eggs of the newt and the dogfish—a neural plate with an expanded front portion is formed which gives rise to the spinal cord and brain. Eyes, ears, and nose appear in the normal way, and so also do gill-slits, which from the beginning are open slits in the throat. The upper parts of the mesoderm bands become divided into myotomes; the lower parts split so as to form the splanchnocœle. Between the edges of the right and left splanchnocœles in front the heart appears as a space just as it does in the dogfish [Plate III. (*v*)].

But there are certain peculiar features which appear at this stage (on the third day after incubation) and influence the whole future course of development—and these features recur in the development of all the mammals, including Man himself. On the surface of the spreading skin of ectoderm—which, as we have seen, corresponds to the ventral and lateral lips of the blastopore—a semicicular fold appears both in front of the brain and behind the tail bud of the embryo. These folds do not involve the endoderm skin beneath them, but the mesoderm bands, with their cavities constituting the splanchnocœle extend into them. These folds are called the *amniotic folds*. By the fourth day the front and back folds have met over the embryo and veiled it from view. The outer limbs of the folds join and form a membrane closely pressed against the vitelline membrane, which is called the chorion or *false amnion,* whilst the inner folds meet to form a membrane termed the *true amnion.* Between false and true amnion there is an extension of the splanchnocœle, whose walls are covered with a network of blood-vessels. Inside the cover of the true amnion the body of the future bird begins to be folded off from the yolk-sac. There is an outer set of folds which define the outlines of the body called the *somatopleuric* folds; by the growth of these the head and tail begin to project freely over the yolk-sac. There are, however, also an inner set of folds called the *splanchnopleure,* which define the alimentary canal; these are separated from the somatopleuric folds by the cœlom or body-cavity. The pharynx in front and the hinder part of the intestine behind are soon completely folded off. Then from the under surface of this part of the intestine there arises a bladder; this bladder grows rapidly; pushing the inner wall of the splanchnocœle before it, it penetrates between false and true amnion and eventually forms a great umbrella-like hood over the embryo; it is richly supplied with bloodvessels carried by the mesoderm, which clings to it. This structure is called the *allantois;* it is formed in the development of all reptiles, birds, and mammals. In the bird it serves as a breathing organ. The egg-shell is porous and at one end the albumen (white) shrinks away from it and air filters in. Through the thin vitelline membrane and false amnion this air diffuses so as to reach the blood-vessels of the allantois, and so oxygen is carried all over the body of the embryo. The allantois begins to grow on the fourth day, and has reached its full development by the seventh and eighth days.

It is almost impossible in the present state of our knowledge to imagine the various steps which led to the formation of these extraordinary organs, but they are so constant in all the higher forms that reptiles, birds, and mammals are grouped together as *Amniota.* The bird has no urinary bladder and the allantois shrivels up when it hatches, but the stump of the allantois remains as the permanent bladder in reptiles and mammals.

A third peculiar feature about the embryo chick, which differentiates it from amphibia and fish, but which it shares with reptiles and mammals, is the *cervical flexure.* The head of the embryo is bent on the trunk at an angle of almost 150°. The result of this flexure is that a number of myotomes (five behind the ear capsule) are crushed together and eventually become incorporated in the hinder region of the skull, which is longer than the skull of an amphibian. In the frog or the newt only one myotome behind the ear capsule is added to the skull.

In the general development of its internal organs the development of the chick is the same as that of the frog or newt, but as developing chicks can be easily obtained by artificial incubation, we may carry the story of the development of the organs a little farther than we did in the case of the amphibian. The open gill-slits of the third-day embryo soon become closed, but they do not close individually as they do in the newt. They become tucked into a pit called the *cervical sinus* and a fold of skin grows over them; this pit obviously corresponds to the branchial chamber of the tadpole of the frog.

The first gill-slit, however, does not share this fate; it persists, only its outer aperture becoming closed with membrane, and it is converted into the Eustachian tube or middle ear, the membrane closing it changing into the ear-drum. The lungs arise as a pair of small pouches immediately behind the gill-slits, and represent a last pair of these which do not open to the exterior. The alimentary canal grows more quickly than the rest of the body, and so becomes folded into a series of loops. The first of these loops forms the stomach. Behind this a single tube grows out and downward, which is the rudiment of the liver. The liver remains throughout life in this condition in Amphioxus. In the chick, as in Amphibia, this tube branches repeatedly, and the branches reunite at their ends to form a closely woven network, and the whole mass bulges into the splanchnocœle as a spongy mass which soon assumes the consistency of the adult liver. The kidney arises as a series of little vesicles in the loose mesoderm, between the myotomes above and the splanchnocœle below. From these vesicles S-shaped pillars of cells grow out which form the *kidney tubules*. From the state of affairs in the dogfish we conclude that these vesicles are intermediate parts of the cœlom, which originally connected myocœle and splanchnocœle, and at first there is only one to each myotome. But the vesicles possess the power of budding off new vesicles, and soon a thick mass of these vesicles is formed which, with the tubes which sprout from them, make up the adult kidney. The kidney duct or *ureter* seems to be made up by the joining together of the outer parts of the kidney tubules.

Whilst the growth of organs has been going on inside the embryo body this body has become more and more deeply folded off from the yolk. By the ninth day it is quite obviously a small bird in whose skin the rudiments of feathers are making their appearance, and from that day until hatching the principal changes which supervene are an increase in size of the bird and a decrease in size of the yolk-sac. In order to understand the final stages we may now glance more closely at what is happening to the yolk. The blastoderm, *i.e.* the skin of ectoderm which represents the ventral lip of the blastopore, spreads ever farther downwards towards the lower pole of the egg. Underneath it, lagging a little behind it, endoderm cells continue to be formed in the superficial layer of the yolk. Between the two, lagging behind both these layers, spread the lower edges of the mesoderm bands. As these bands extend downwards, so does the network of bloodvessels on the surface of the endoderm which is formed beneath them, and so, too, does the cœlom, which cleaves the mesoderm into an outer or somatic, and an inner or splanchnio layer. The cœlom leads directly into the space between true and false amnion, into which the allantois projects. The white or albumen which originally invested the whole egg shrinks more and more till it forms a mass lying near the lower pole of the egg. This mass is finally pushed into the yolk-sac and then, and then only, does the advancing endoderm completely cover in the yolk.

As the cœlom extends towards the lower pole of the egg it cuts off completely the yolk-sac from contact with the ectoderm, and the allantois, like a huge mushroom, grows step by step with the cœlom; it is really the edges of the enormous allantois which grow round and push the remainder of the white into the yolk-sac.

The outer walls of the body are moulded by the deep fold which separates the inner, or true, amnion from the skin of the embryo. The space between embryo and amnion is known as the *amniotic cavity*. This cavity on the fourth day is a narrow slit, but about the sixth day the embryo begins to rock from side to side, and this rocking movement seems to be associated with the secretion of more and more fluid. This fluid forces the amnion away from the embryo and deepens the groove separating the two, thus outlining the embryonic body and at the same time providing a space for the expansion of the limbs (wings and legs), the rudiments of which have appeared as low ridges as early as the fourth day.

As hatching approaches and the flanks of the bird are more and more clearly marked out by the deepening amniotic grooves, the diminished yolk-sac, now surrounded by endoderm, is folded off from the intestine by the splanchniopleuric folds, and only remains connected to it by a narrow duct called the *vitelline duct*. Eventually the little yolk-sac is completely taken up into the body-cavity of the embryo and the abdominal walls come together in a seam which is the *navel*. The union of these walls cuts off the stalk of the allantois, and as the chick steps out of the broken egg-shell it leaves behind it the shrivelled remains of the allantois and of the amnion.

CHAPTER VI

THE DEVELOPMENT OF MAMMALS

Mammals are warm-blooded animals covered with true hair, with sweat glands and oil glands in the skin; they nourish their young in the womb before birth, and after birth feed them with milk produced by special glands called milk glands. We ourselves are mammals, and so are all our common domestic animals, such as horses, cattle, sheep, goats, pigs, rabbits, as well as hosts of wild ones, including those most sought after by big-game hunters. We propose, therefore, to conclude this book with a short sketch of mammalian development which will give some idea of our own life within the maternal womb. Mammals are Amniota, that is, members of the same stock as that to which reptiles and birds belong. There are still two mammals surviving, viz. the duck-billed mole (Ornithorhyneus) and the spiny ant-eater (Echidna), both natives of Australia, which lay yolky eggs within horny shells, the development of which is in all essential respects similar to that of the hen's egg. But the development of these eggs has gone a considerable distance before they are laid, and they have already learned the trick of absorbing nourishment from the mother. They swell up during their passage down the oviduct by absorbing the exudations of its walls, which diffuse through the porous shell.

All other Mammalia produce minute eggs from which practically all traces of yolk have disappeared. These minute eggs are fertilized by ascending spermatozoa in the upper part of the oviduct, which is called the *Fallopian tube*. During their passage down it they undergo segmentation. In the lower part of the oviduct, which is enlarged and called the womb, the embryos swell up and are converted into little vesicles, the so-called *blastodermic vesicles*. These vesicles acquire an adhesion to the womb wall; in each the outer layer of cells becomes modified into an organ called the *placenta*, which is adapted to absorb nourishment from the maternal bloodvessels with which the womb is richly supplied. Once this organ is established, the embryo grows rapidly in size and weight. The womb is provided with powerful muscles, and when the embryo is ready for birth it is expelled by strong contractions of these, which produce the so-called labour pains.

The later stages of human development have been studied in great detail, so that more is known of the development of the human organs than of those of any other mammal, but of the earlier stages very little is known, because the opportunities of observing them are so rare. In the lower mammals such as the rabbit these stages are better known, but even in these cases our knowledge is small indeed compared with our knowledge of the early stages in the frog and newt. If we kill a female rabbit which has just conceived, we may with luck find a dozen eggs in different stages of segmentation inside her. A female frog will produce several thousand eggs at the same time.

In the rabbit the egg, when shed from the ovary, is one-fiftieth of an inch in diameter, rather larger than the egg of Amphioxus. It does not, however, produce a blastula. Remembering its origin from a larger egg well provided with yolk, it gives rise to a little solid mass of cells which is called a *morula*. This probably represents a blastula with greatly enlarged cells at one side, an exaggeration of the state of affairs in the newt. Just before the egg reaches the womb a cap of small cells can be seen at one side which appears to spread over the larger cells and nearly surround them [Plate III. (*w*)]. Then when the egg enters the womb it absorbs fluid and swells up into a thin vesicle about the size of a pea [Plate III. (*x*)]. The wall of this vesicle is composed of a single layer of flattened cells, but to one side clings a group of cells, called the *lower layer cells;* these are the large cells of an earlier stage. The vesicle now develops a series of pegs on its outer surface, and these fit into pits in the womb wall, the so-called uterine glands. This layer of cells absorbs nourishment from the mother and is called the *trophoblast.*

Before this happens, however, the trophoblast thins out over the lump of lower layer cells and becomes amalgamated with the outmost of these; the rest spread out under the trophoblast in a comparatively thin layer and form the endoderm. Where the trophoblast fuses with the lower layer cells we soon descry the familiar appearance of an area pellucida with a primitive groove in its centre; and the formation of the embryonic germinal layers and of the embryonic organs follows on the same lines as those described in the development of the hen's egg.

We can now plausibly interpret the earlier stages of development. The morula represents a modified blastula with relatively large cells at the vegetative pole. Possibly some day a trace of the blastocœle may be discovered. The spread of the small cells over these represents the covering of the yolk of the hen's egg with blastoderm; in a word, the growth of the ventral and lateral lips of the blastopore. The "blastodermic vesicle" represents the yolk-sac, the missing yolk being represented by fluid (no doubt containing nutritious material) absorbed from the cavity of the womb. The spread of the inner layer cells represents the gradual differentiation of endoderm at the surface of the yolk in the bird's egg.

We may now notice the changes which supervene after the egg has been firmly attached to the womb wall. From the ingrowth of cells arising from the primitive groove the mesodermic bands are produced which divide into myotomes above and splanchnocœle below. The splanchnocœle extends downwards, penetrating between the ectoderm and endoderm of the blastodermic vesicle, but it *never gets farther than halfway round* [Plate III. (*y*)]. Step by step with its development goes the growth of a network of bloodvessels, into which diffuses the nutritious material derived from the contents of the yolk-sac. This material, in turn, has diffused from the maternal bloodvessels into the yolk-sac through the very thin lower wall of this sac, which is composed of ectoderm and endoderm only. Thus the yolk-sac itself forms an organ for conveying food from mother to embryo, and it is termed the *umbilical placenta*. This organ is not nearly so efficient as the placenta which is formed later, but it is the only one possessed by that curious group of pouched mammals (Marsupials) which make up nearly the whole mammalian population of Australia. These animals, of which the most familiar species are the opossums and kangaroos, retain their young for only a short period in the womb. When born, the embryos are very small and imperfect and scamper through the mother's fur till they get into her pouch; there each attaches itself to one of her teats and remains attached till it has attained the size of one of the newly born young of one of the higher mammals. After this it begins to come out of the pouch and play about, but it still uses the pouch as a home and a retreat, returning to it at frequent intervals for shelter, food, and rest. Returning to the development of the rabbit, we find that the stage at which the umbilical placenta is alone functional is rapidly passed through. The embryo is already being folded off from the yolk by anterior (head) and posterior (tail) folds and lateral folds, these last consisting, as in the chick, of outer somatopleuric and inner splanchnopleuric folds separated by the cœlom.

Two peculiarities, however, discriminate the rabbit's development from that of the chick—first, the allantois begins to bud out at an extremely early period as soon as ever any trace of the hind gut is formed, and, secondly, there is only one amniotic fold enveloped, viz. the tail one, and into this fold the growing allantois at once extends. This amniotic fold extends forwards over the embryo like an umbrella, carrying inside it the allantois. The upper wall of the yolk-sac is rather flaccid, and the head of the embryo indents it, raising a fold beyond the indentation, with which the amniotic fold unites. Thus a true and a false amniotic membrane are produced exactly as in the case of the chick, and the allantois fuses with the false amnion. The allantois carries with it a rich blood supply continuous with the bloodvessels surrounding the hind gut. The area of fusion with the false amnion forms the *allantoic placenta,* which is the most important organ of nutrition of the embryo. In this region the trophoblast sends out very long fingers (*villi*), which absorb the cells of the uterine glands and extend into the soft tissue of the womb wall, and thus come into close proximity to the maternal bloodvessels. Into these fingers grow cores of mesoderm from the outer covering of the allantois, and these cores carry branches from the allantoic bloodvessels [Plate III. (*z*)]. If this description has been followed it will be seen that maternal and embryonic blood are separated only by the layer of ectoderm cells which constitute the trophoblast (in this region the false amnion) and by the thin walls of the maternal bloodvessels. This ectoderm sends out digestive ferments which dissolve the maternal blood corpuscles, and the products of digestion diffuse through the trophoblast into the allantoic bloodvessels. This stage is reached about the tenth day after fertilization, and from this period till birth on the twenty-first day the growth of the embryo is rapid. Both placentas persist; the ever-increasing weight of the embryo indents the flaccid yolk-sac till its cavity is reduced to a slit and its lower wall is absorbed. At the same time, just as in the chick, more and more fluid is secreted between the true amnion and the embryo, thus providing room for the limbs to expand. The body walls come more and more closely together, surrounding and constricting the stalks of the yolk-sac and allantois and outlining the navel. Then the womb begins to contract. The entire trophoblast is wrenched away from the womb wall, laying bare the maternal blood spaces. As the trophoblast passes down the vagina it bursts, discharging the amniotic fluid (the waters) and exposing the embryo, which comes into the world dragging behind it the navel cord connected with the remains of the placentas. It is roughly true that the mammal endeavours to lay an egg which is broken in the act of hatching. The wound in the womb wall is rapidly closed by the contracting of the womb muscle, and thus dangerous bleeding is prevented.

We may now take a rapid survey of some other mammalian developments which lead up to the development of the human baby. In the dog and cat the allantoic placenta is at first in the form of a disc or umbrella, as in the rabbit. But the splanchocœle extends downwards till right and left splanchnocœles meet at the vegetative pole of the yolk-sac, completely cutting this off from contact with the trophoblast, and so the umbilical placenta ceases to exist; the useless yolk-sac is soon absorbed; the allantoic placenta takes the form of a broad belt round the middle of the trophoblast. Such a placenta is termed a *zonary* one. There are curious creatures called lemurs which live in Madagascar, in which the first beginnings of the ape may be discerned, and which are consequently the lowest members of the special group of mammals which includes Man. In these creatures the yolk-sac is absorbed at a still earlier period of development than in the dog and cat, and the allantoic placenta extends not merely round the trophoblast, but all over it, so that its whole surface is covered with villi. Such a placenta is termed a *diffuse placenta.* Since in the lemurs only one baby is produced at a time and this baby occupies the whole cavity of the womb, it follows that at birth, a large surface of maternal bloodvessels is exposed, and the consequent bleeding might be fatal were it not that the villi are short and simple and penetrate only to the uterine glands of the mother. In the human being the development of the baby follows the same general course as in the lemur up to the end of the first three months of pregnancy, and it is common knowledge that during this period premature birth (abortion) is not usually followed by serious bleeding. But in the fourth month a change supervenes. Over a disc-like area at the vegetative pole of the egg the villi become much larger and more branched, whilst over the rest of the surface of the trophoblast they dwindle and disappear. This area is the *metadiscoidal placenta* [Plate III. (z′)] of apes and Man, not to be confounded with the simple discoidal placenta of the rabbit, which is dorsal to the embryo. After this placenta has been established, abortion is a much more dangerous affair than before it. This placenta is expelled from the womb about ten minutes after the baby is born, and is the so-called *after-birth* around which so many primitive superstitions have grown up. Sometimes a portion of true amnion is carried into the world adhering to the baby's head; this is the "caul" (see *David Copperfield*), supposed to be a charm against death by drowning.

It will thus be seen that the development and birth of a human baby is a very complicated affair involving the harmonious working together of many processes. Owing to various poisons in the mother's blood derived from alcohol or the germs of venereal disease, this harmony may be disturbed and a wretched malformed baby may be brought into the world. Into the causes of these various malformations it is impossible to go within the narrow limits of this book; but there is one which is responsible for more crippling disfigurements than any other, and we may devote a few words to it. We have seen that the true amnion, when first formed, is closely wrapped round the embryo, but that it is gradually forced away by the secretion of amniotic fluid. This secretion is associated with rocking movements of the embryo in the case of the chick, and probably also in the case of the mammal, though naturally this cannot be proved. If by poisons the secretion of this fluid is slowed down, the amnion continues to cling to the embryo, and, according to the period of development at which this occurs, different types of disastrous malformations are produced. At an early period it may stop the development of the head, and a brainless baby is produced which dies immediately on birth. If the pressure comes later and is not so great, the head may be compressed in an antero-posterior direction, and thus the so-called Mongolian idiot is produced which sometimes survives to a mature age. Less extensive pressure may stop the development of arms or legs; there is an armless lady artist in Geneva who paints with her feet. Lastly, still slighter amniotic constrictions occurring at a later period may interfere with the development of fingers and toes. Sometimes some of these are suppressed, and so a child with three fingers on one hand is produced; but equally often one finger rudiment is cleft into two, and thus six-fingered and six-toed people come into existence. So we see that the most varied "sports" may be due to differing intensities of the same weakness, and there is evidence that this weakness, however first caused, is often hereditary. There is strong evidence that "mutations," so dear to the heart of the "geneticist," are examples of the same kind of phenomenon, and, as we have shown at length in our volume on *Evolution,* these mutations have no bearing whatever on that secular racial change of animals which is real evolution.

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UNFORTUNATELY nearly all the textbooks on this subject are large and couched in very technical language. Forty years ago textbooks of a more popular character existed, but they have all gone out of print.

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EXPLANATORY NOTES TO PLATES

PLATE I.

(*a*) Egg of Sea-Urchin being Fertilized.

1, Egg nucleus; 2, primary egg-shell (vitelline membrane); 3, successful spermatozoon entering the egg.

(*b*) Egg of the Slipper-Limpet Crepidula preparing to Divide into Two.

1, Maternal chromosomes; 2, paternal chromosomes; 3, "asters" at each end of the dividing nucleus.

(*c*) Egg of the Slipper-Limpet in the Act of Division.

1, 2, 3, as in previous figure.

(*d*) Blastula Stage of the Development of the Sea-Urchin.

(*e*) Gastrula Stage of the Development of the Sea-Urchin.

1, Blastopore leading into cavity of invagination or primitive gut (archenteron); 2, mesenchyme cells being budded off.

(*f*) Late Gastrula Stage of the Development of the Sea-Urchin.

1, Blastopore leading into archenteron; 2, cœlomic vesicle.

(*g*) Flattened Blastula Stage in the Development of Amphioxus.

1, Abrupt transition of large cells (macromeres) into small cells (micromeres) marking the position of the zone of growth.

(*h*) Early Gastrula Stage in the Development of Amphioxus.

1, Zone of growing cells; 2, cavity of invagination (archenteron).

(*i*) Late Gastrula Stage in the Development of Amphioxus.

1, Dorsal zone of growing cells; 2, ventral zone of growing cells; 3, blastopore.

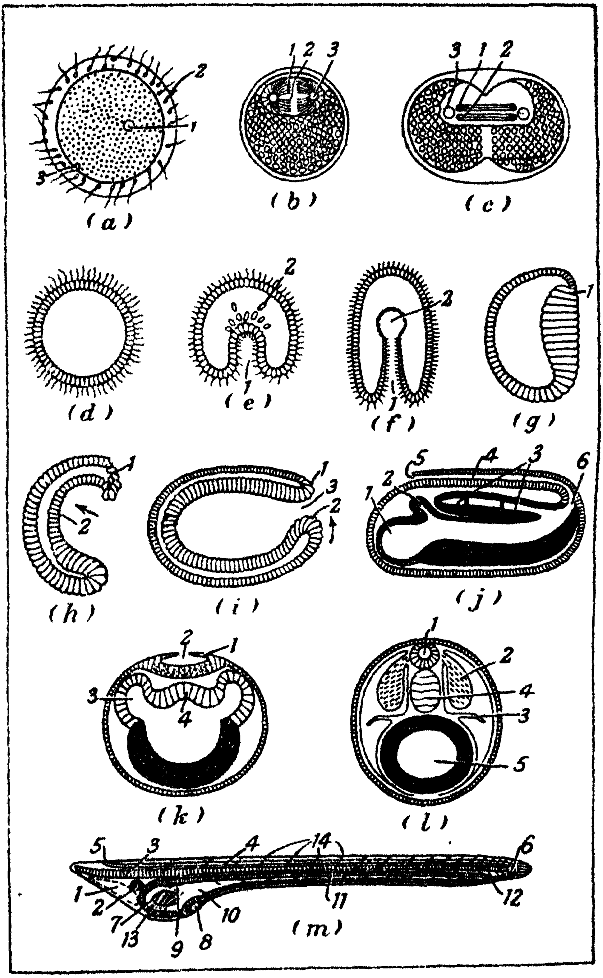
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PLATE I.

(*j*) Early Embryo of Amphioxus in Logitudinal Section.

1, Swelling of primitive gut (archenteron), which will later form the head-cavities; 2, pouch forming collar cavity; 3, cœlomic groove, the front part of which is already dividing into somites; 4, neural canal; 5, neuropore; 6, neurenteric canal.

(*k*) Transverse Section of Early Embryo of Amphioxus.

1, neural flap; 2, neural canal; 3, cœlomic groove; 4, rudiment of notochord.

(*l*) Transverse Section of Late Embryo of Amphioxus.

1, neural canal; 2, myotomic muscles; 3, imperfect septum dividing cavity of myotome (myocœle) from the splanchnocœle; 4, notochord; 5, intestine.

(*m*) Side View of a Young Larva of Amphioxus.

1, Right head-cavity; 2, left head-cavity (Hatschek's pit); 3, notochord; 4, spinal cord; 5, neuropore; 6, neurenteric canal; 7, mouth; 8, first gill-slit; 9, club-shaped gland; 10, cavity of pharynx; 11, intestine; 12, anus; 13, rudiment of endostyle; 14, septa dividing myotomes from one another.

PLATE II.

(*n*) Longitudinal Section of the Gastrula of a Newt.

1, Blastopore; 2, ectoderm; 3, dorsal zone of growth in the lip of the blastopore; 4, ventral zone of growth.

(*o*) Young Larva of Newt seen from the Right Side.

1, Eye; 2, nose; 3, "balancer"; 4, 5, 6, external gills; 7, rudiment of fore-limb; 8, rudiment of the hind-limb; 9, tail.

(*p*) Compound Monster (Chimæra) Produced by Grafting a Small Piece of the Blastopore Lip of the White Gastrula of *Triton cristatus* on the Flank of the Brown Gastrula of *Triton tæniatus*.

1, Fore-brain; 2, 3, eye-rudiments of *Triton tæniatus;* 4, myotomes of *Triton tæniatus;* 5, nerve-plate formed by influence of *Triton cristatus;* 6, myotomes of *Triton tæniatus;* 6, myotomes formed by the influence of *Triton cristatus.*

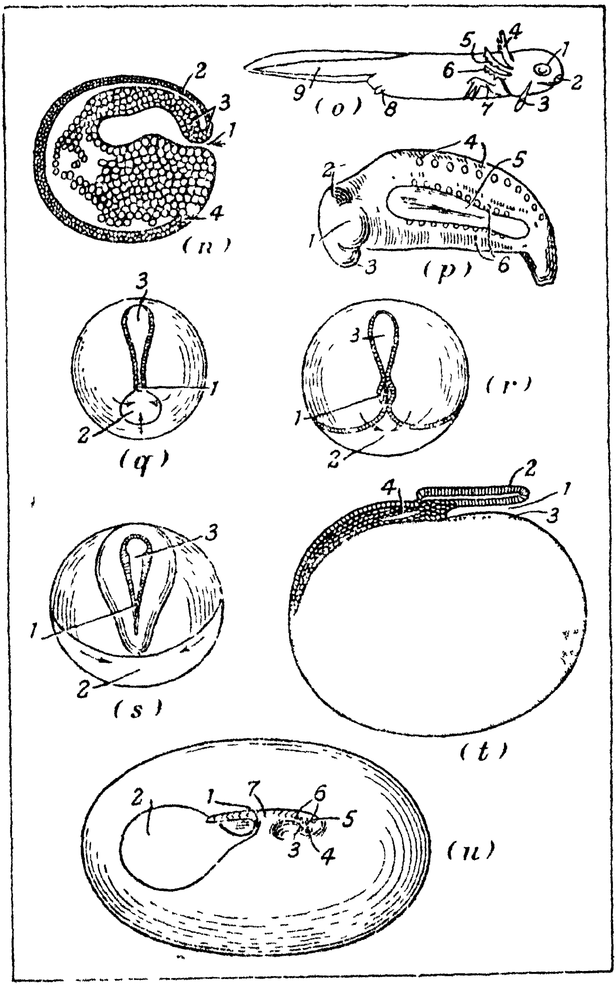

PLATE II.

(*q*) Upper View of the Gastrula of a Newt in the Stage when the Blastopore is nearly closed.

1, Upper part of blastopore; 2, lower part of blastopore; 3, neural plate.

(*r*) Upper View of the Gastrula of a Dogfish.

1, Upper part of blastopore; 2, lower part of blastopore; 3, neural plate.

(*s*) Upper View of the Gastrula Stage of a Chicken.

1, Upper part of blastopore; 2, lower part of blastopore; 3, neural plate.

(*t*) Longitudinal Section of the Gastrula of a Dogfish.

1, Blastopore; 2, neural plate; 3, nuclei embedded in unsegmented protoplasm representing the large lower cells of the gastrula of the newt (*n*); 4, disappearing blastocœle (segmentation cavity).

(*u*) Lateral View of the Developing Egg of the Dogfish when the Embryo is being grooved off from the Yolk-sac.

1, Upper part of blastopore; 2, lower part of blastopore; 3, nose, 4, eye; 5, ear; 6, gill-slits; 7, myotomes.

PLATE III.

(*v*) View of the Embryo of a Chicken from an Egg which has been Incubated for Four Days. The Embryo is twisted so that its head lies with the left side down.

1, Fore-brain; 2, mid-brain; 3, hind-brain; 4, cerebral hemispheres (outgrowth from fore-brain); 5, nose; 6, eye; 7, ear; 8, pituitary outgrowth of mouth-cavity beneath fore-brain; 9, mouth-cavity; 10, 11, 12, 13, the four gill-slits; 14, heart; 15, the two large veins (vitelline veins) which by their union in front make up the heart; 16, tail-bud; 17, myotomes; 18, edges of amniotic fold.

(*w*) Early Stage in the Developing Egg of a Rabbit whilst it is passing through the upper part of the oviduct (Fallopian Tube).

1, Cover of small investing cells; 2, deep mass of larger cells.

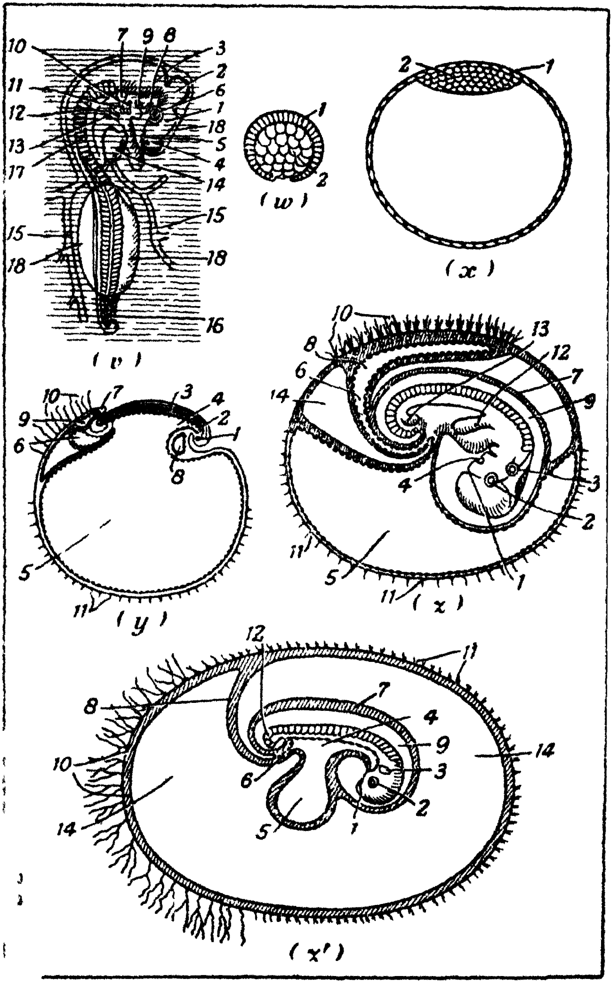
7 9 8
(v)
(w)
(x)
(y)
(z)
(x′)

Plate III.

(*x*) Later Stage in the Developing Egg of a Rabbit when it has reached the lower part of the oviduct (Womb) but has not yet attached itself to its Walls.

1, 2, As in previous figure.

(*y*) Embryo of Rabbit shortly after it has effected an attachment to the wall of the womb.

1, Eye; 2, spinal canal; 3, notochord; 4, fore-gut; 5, yolk-sac; 6, allantois; 7, amniotic fold; 8, pericardial portion of the cœlom; 9, extra-embryonic cœlom protruding into the amniotic fold; 10, enlarged villi of the region of the placenta; 11, small trophoblastic villi.

(*z*) Older Embryo of Rabbit.

1, Nose; 2, eye; 3, ear; 4, mouth; 5, yolk-sac; 6, stalk of allantois; 7, true amnion; 8, allantois; 9, amniotic cavity; 10, enlarged villi of placental region; 11, small trophoblastic villi; 12, rudiment of fore-limb; 13, rudiment of hind-limb; 14, extra-embryonic cœlom into which the allantois grows.

(*z'*) Diagram of the Early Embryo of a Human Being.

1, Nose; 2, eye; 3, ear; 4, alimentary canal; 5, yolk-sac; 6, degenerate allantoic bladder; 7, amnion; 8, stalk of allantois along which bloodvessels extend to the placenta; 9, amniotic cavity; 10, elongated villi of the discordal placenta; 11, small villi of the earlier diffuse placenta; 14, extra embryonic cœlom.